

Particulate Air Quality and Emissions Trends in the Southeast

Ryan Brown, Daniel Garver, and Stacy Harder

U.S. EPA Region 4

April 28, 2011

Introduction

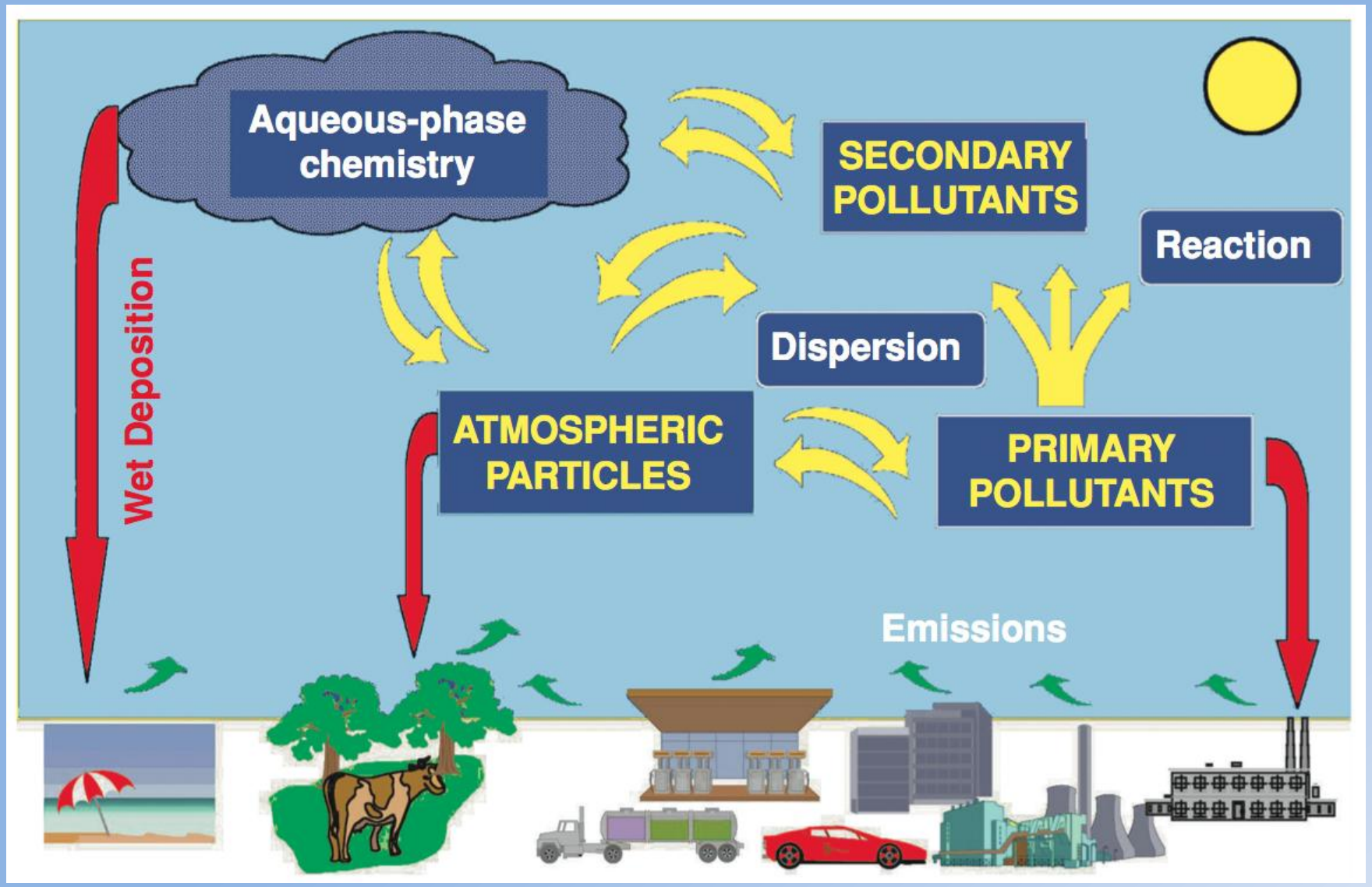
- Noticed decreasing $PM_{2.5}$ design values starting in 2008
- Sulfate trends analysis in 2009
  - 3 cities: Atlanta, Birmingham, Chattanooga
  - Statistically significant downward trend in winter, spring, and fall
  - Decrease in 2008 summer concentration, but not a statistically significant trend
- Current $PM_{2.5}$ speciation trends analysis
  - Examine link between emissions and monitoring data
  - Use most current and inclusive datasets available

Outline

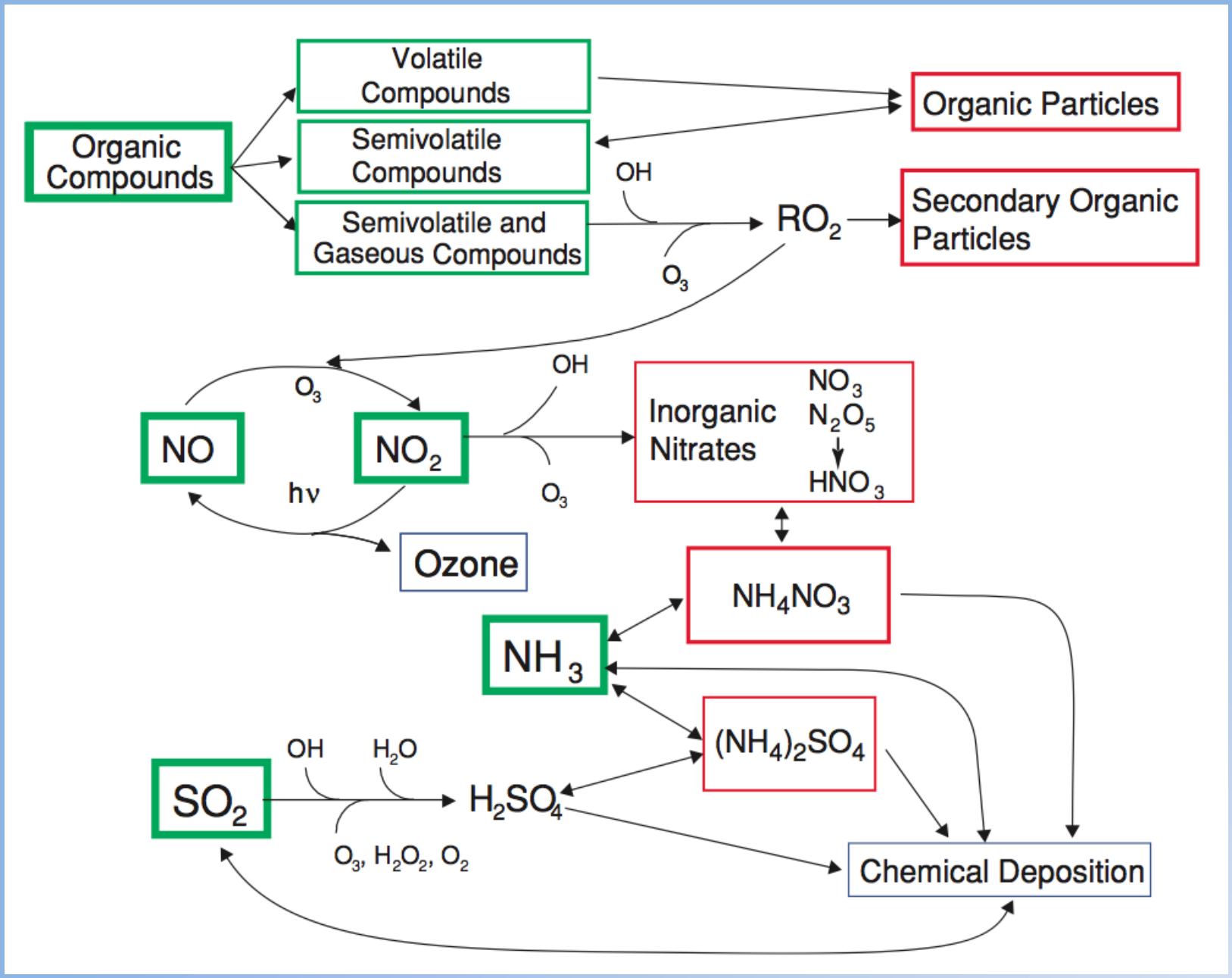
- Atmospheric chemistry overview
- Regulatory background
- Emissions trends: PM and precursor gases
- Air quality trends: $PM_{2.5}$ speciation network
- Conclusions

ATMOSPHERIC CHEMISTRY

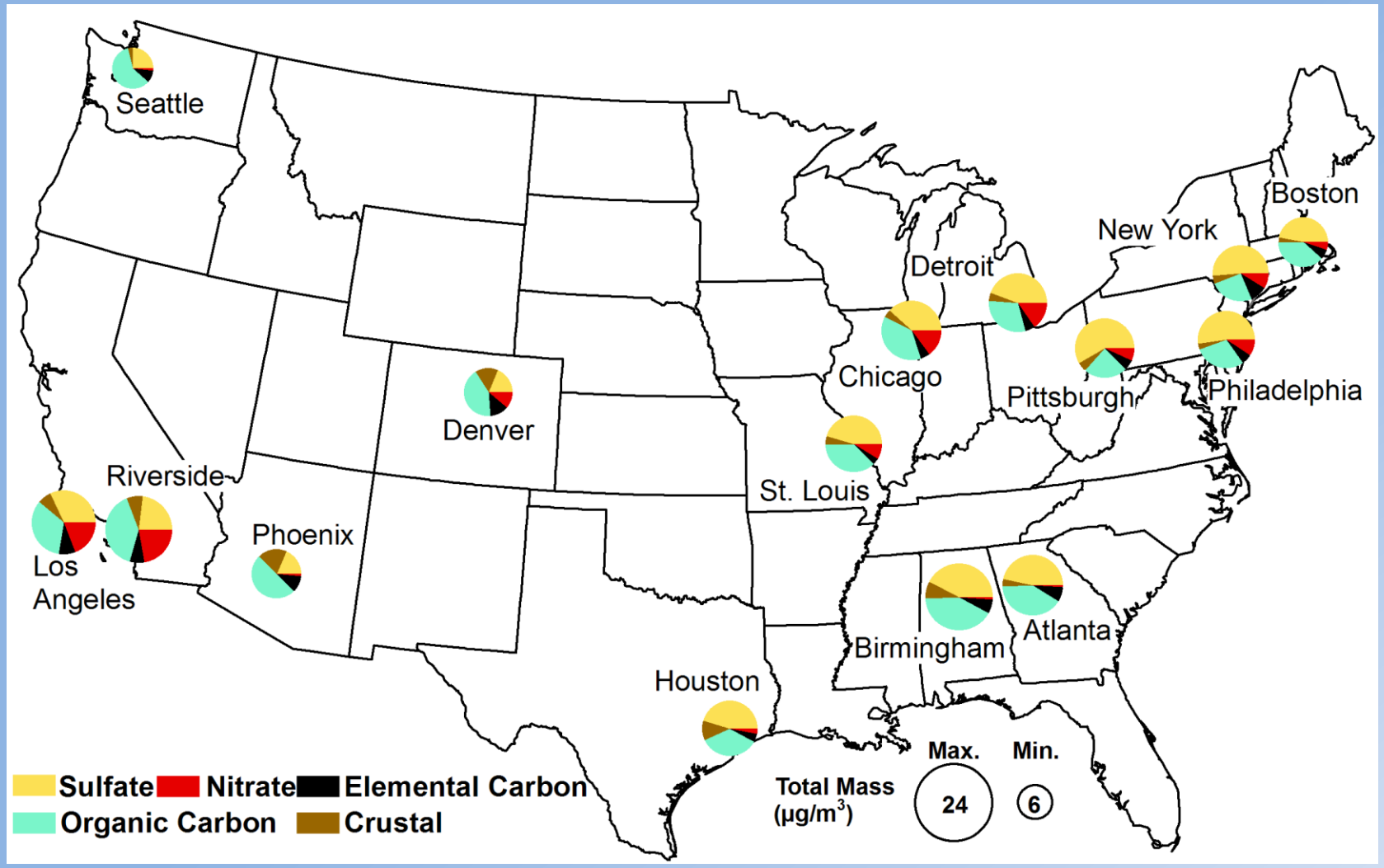
Particle Formation Overview



NARSTO. 2004. Particulate Matter Assessment for Policy Makers: A NARSTO Assessment.



NARSTO. 2004. Particulate Matter Assessment for Policy Makers: A NARSTO Assessment.



EPA Report: Our Nation's Air - Status and Trends through 2008

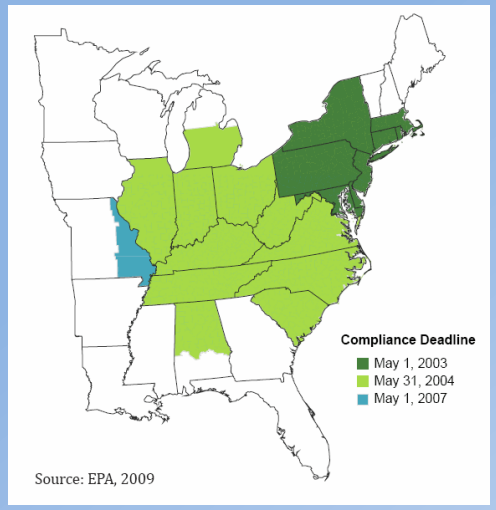
Atmospheric Chemistry

- Increased humidity and solar radiation drive higher rates of sulfate formation in the summer
- Lower temperatures and high humidity favor nitrate formation -> formation greater in the winter and in the northeastern U.S.

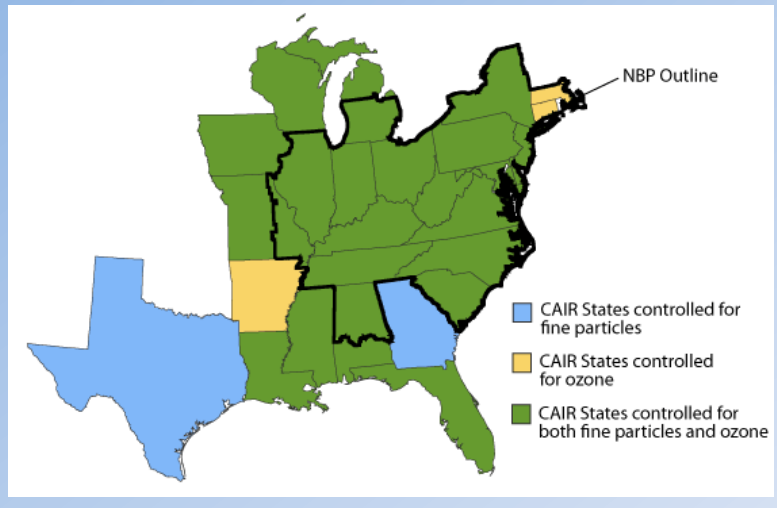
REGULATORY BACKGROUND

Regulatory Background – Cap and Trade Programs for SO_2 and NO_x

- Acid Rain Program
- NO_x Budget Trading Program (NO_x SIP Call)
- Clean Air Interstate Rule
- Proposed Transport Rule



NO_x SIP Call States



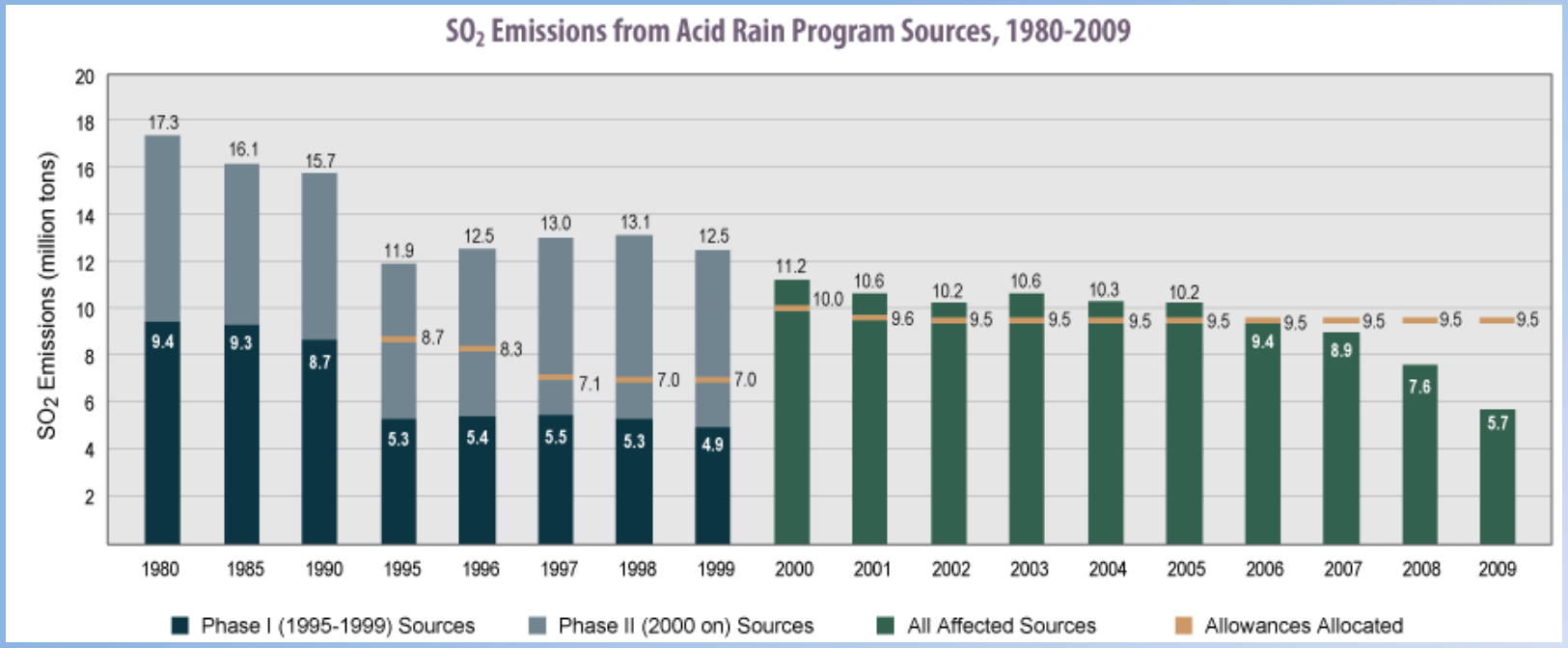
CAIR States

Acid Rain Program (ARP)

- Regulated under Title IV of the Clean Air Act
  - Two-phase restriction on fossil fuel-fired power plants
  - Reduce annual SO_2 emissions by 10 million tons below 1980 levels
- 1995 – Phase I
  - Affected 263 units at 110 mostly coal-burning electric utility plants in 21 eastern and midwest states
  - Additional 182 units joined as substitution or compensating units
- 2000 – Phase II
  - Tightened annual emissions limits on large, higher-emitting plants
  - Restrictions on smaller, cleaner plants fired by coal, oil and gas
- Also reduces annual NO_x emissions by 2 million tons by 2000

Acid Rain Program Emissions Reductions

- EPA has phased in the program:
- **1995:** Annual emissions cap of ≈ 10 million tons
- **2000:** New annual cap of 9.5 million tons
- **2010:** New annual cap of 8.95 million tons



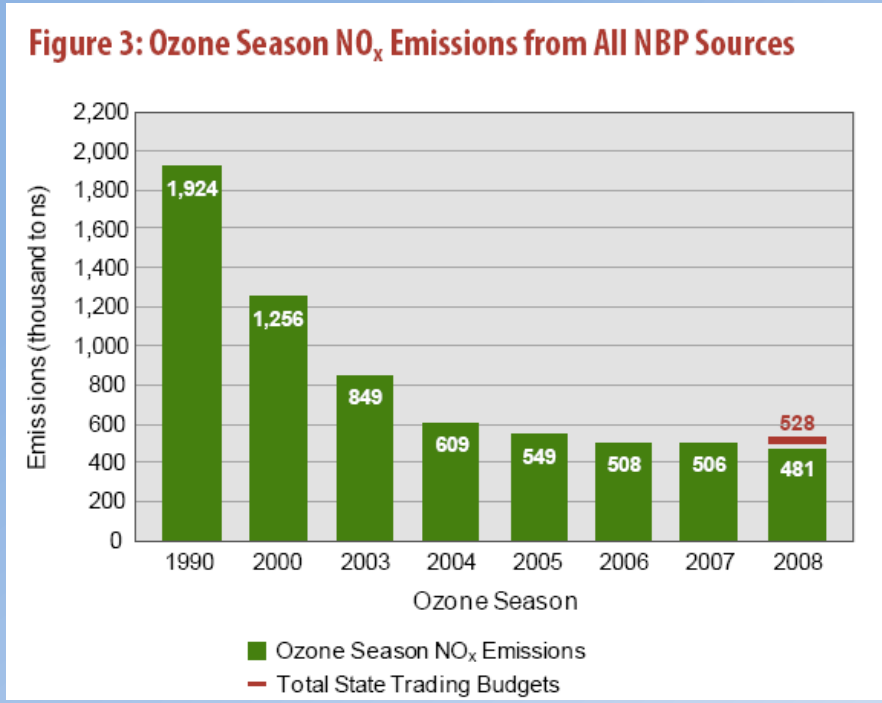
Source: 2009 Acid Rain Program Emission, Compliance, and Market Analyses Report

NO_x Trading Programs

- 1999: Ozone Transport Commission NO_x Budget Program
  - Mitigate significant emissions of NO_x
  - Affects 20 States and District of Columbia
  - Emissions reduction measures were required to be in place by May 1, 2003
- 2003: NO_x Budget Trading Program (NO_x SIP Call)
  - Market based cap and trade program to implement
  - Placed a total NO_x cap in 2008
  - Replaced by CAIR NO_x ozone season program in 2009

NO_x SIP Call Emissions Reductions

- In 2008, NO_x Budget Program sources emitted 481,420 tons of NO_x during the summer ozone season
  - 62% below 2000 levels
  - 75% below 1990 levels
  - 9% below the 2008 cap



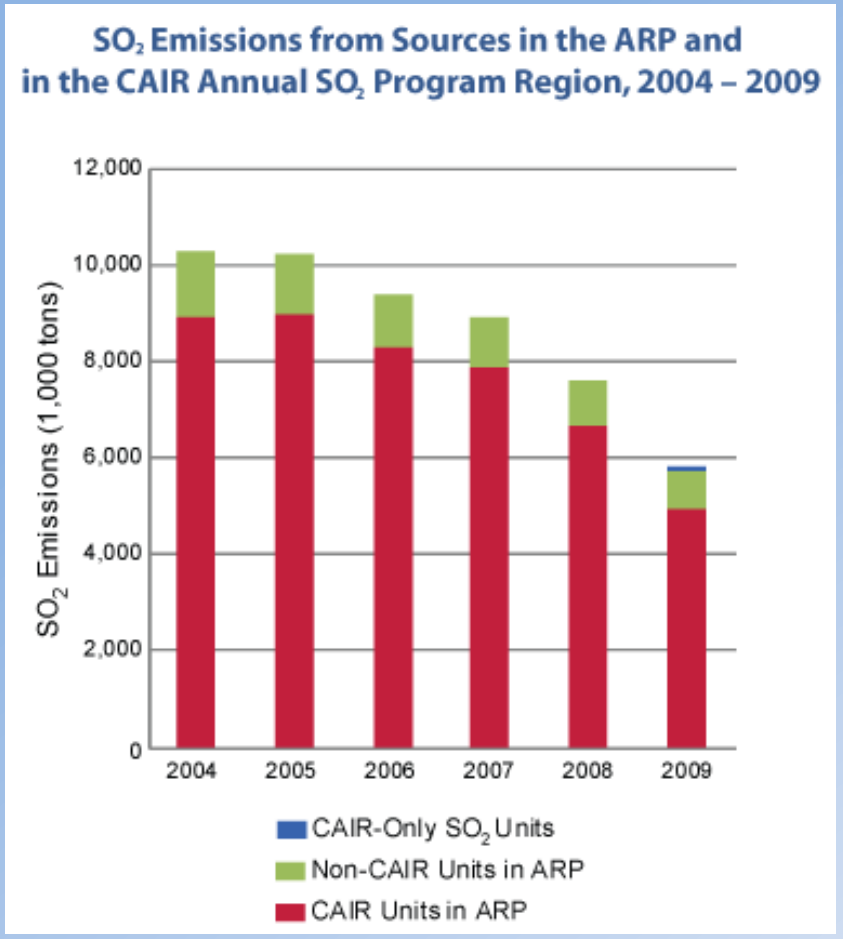
Source: 2008 NO_x Budget Trading Program Emission, Compliance, and Market Analyses Report

Clean Air Interstate Rule (CAIR)

- March 10, 2005 - Issued
  - Intended to achieve largest reduction in air pollution in over a decade
  - Permanently cap emissions of SO_2 and NO_x in Eastern United States
  - When fully implemented - reduce SO_2 emissions by over 70% and NO_2 by over 60% from 2003 levels
- July 11, 2008 – Vacated and remanded
- December 23, 2008 – Court remanded rules to EPA
  - Leaves rules in place until EPA issues a replacement rule
- July 6, 2010 – Proposed Transport Rule
  - Once final, will replace CAIR starting in 2012
  - Would allow intrastate and limited interstate trading among power plants but assure that each state will meet its pollution control obligations

CAIR Emissions Reductions

- Includes a two-phase program with declining power plant emission caps:
- SO_2 annual total emissions caps ≈ 5.9 million tons in 2010 and ≈ 3.4 million in 2015
- NO_x annual total emissions caps ≈ 1.6 million tons in 2009 and ≈ 1.3 million in 2015
- Emission caps are divided into state SO_2 and NO_x budgets

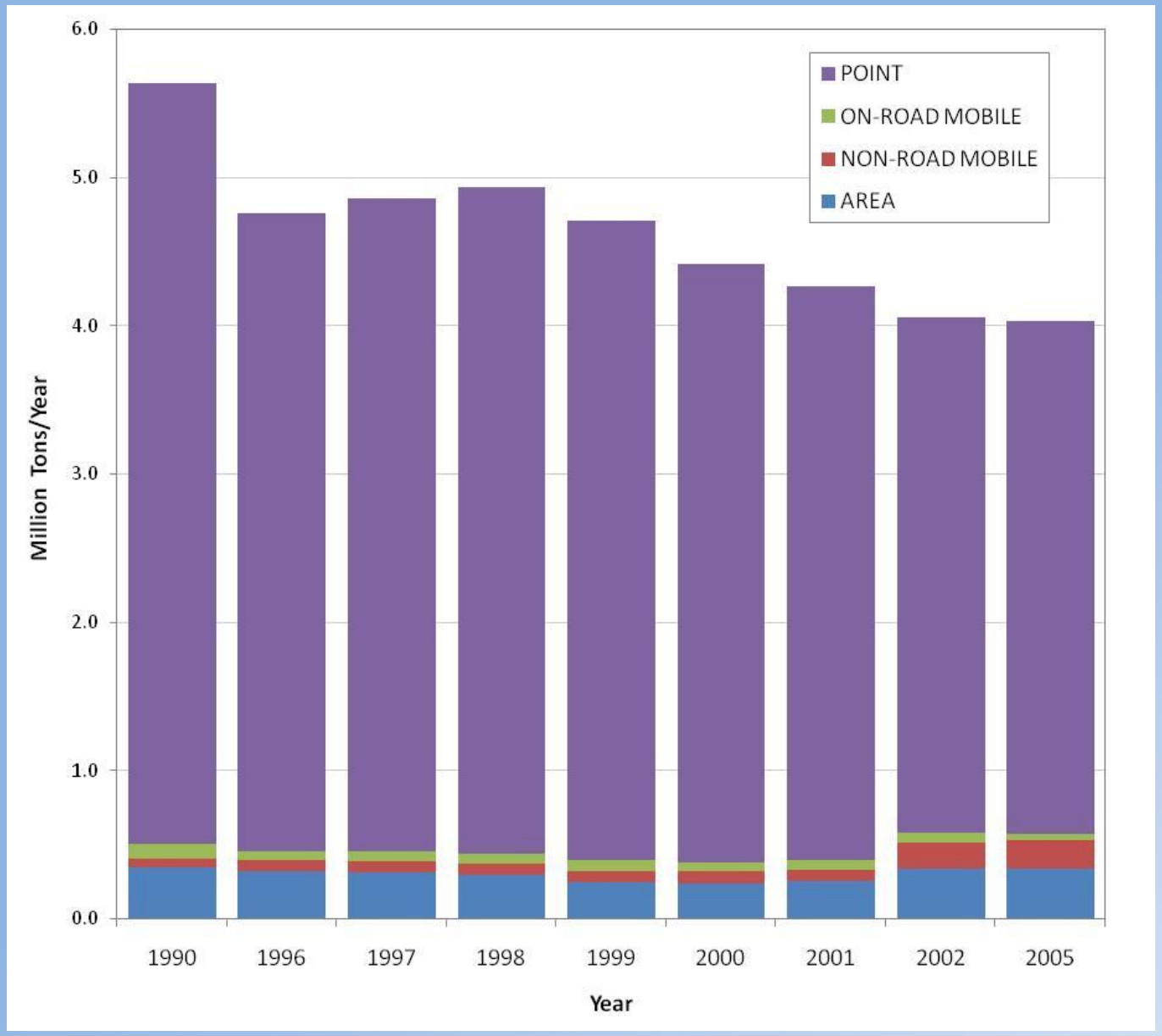


Source: 2009 CAIR Emission, Compliance, and Market Analyses Report

EMISSIONS TRENDS

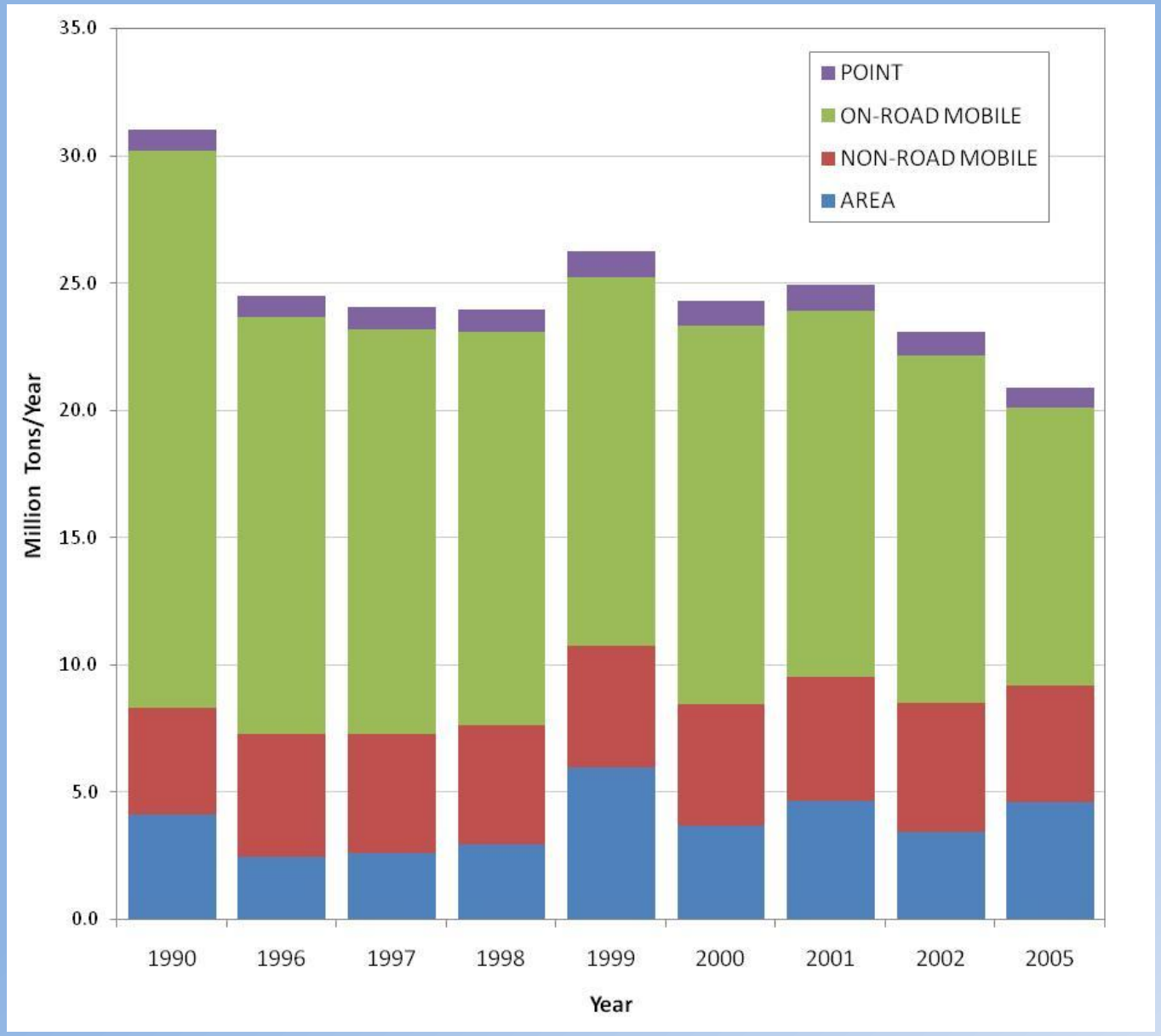
Particulate Matter and Precursor Gases

SO_2 Emissions by Source Category in the Southeast, 1990-2005



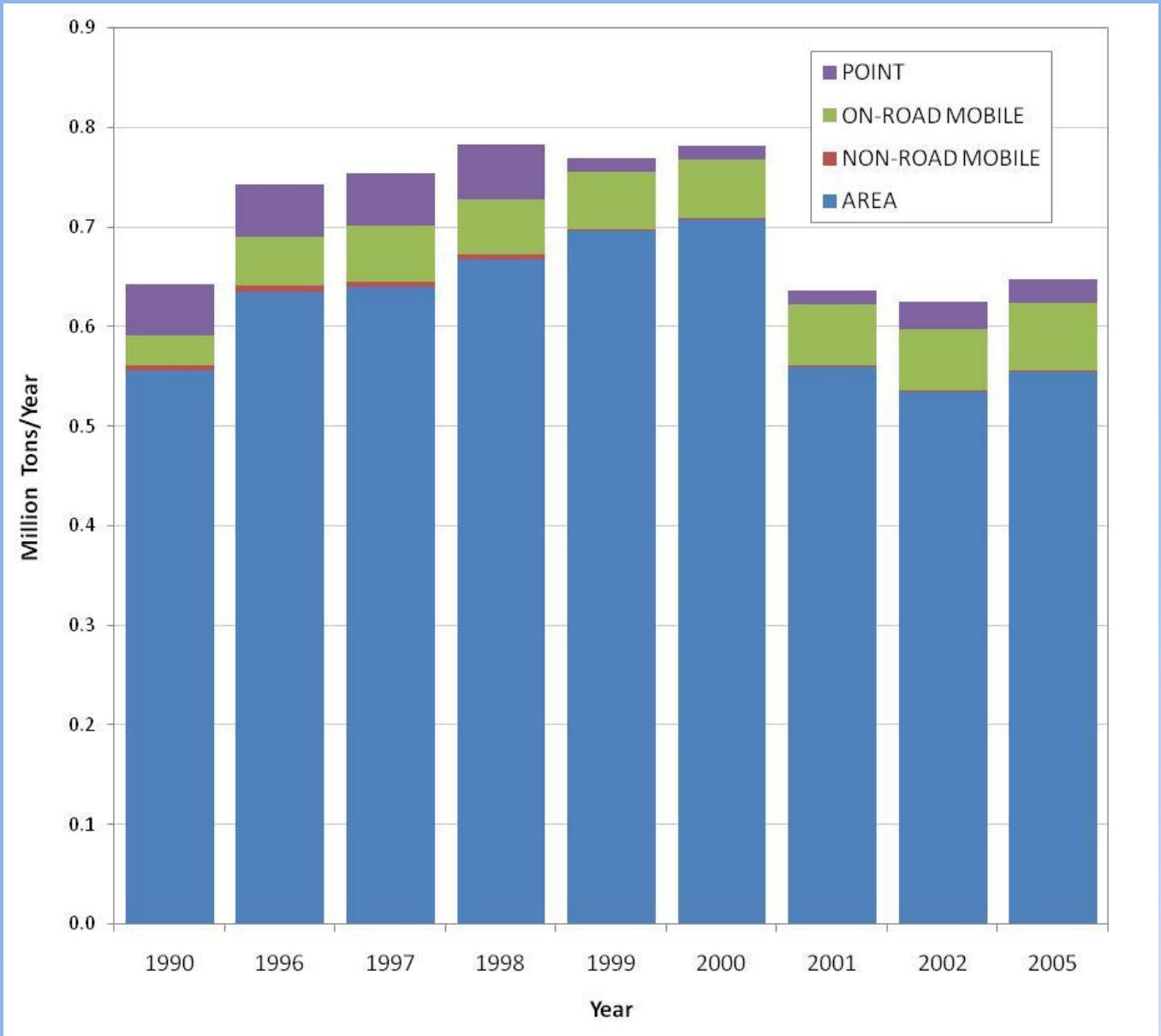
Source: 1990-2005 National Emissions Inventory

CO Emissions by Source Category in the Southeast, 1990-2005



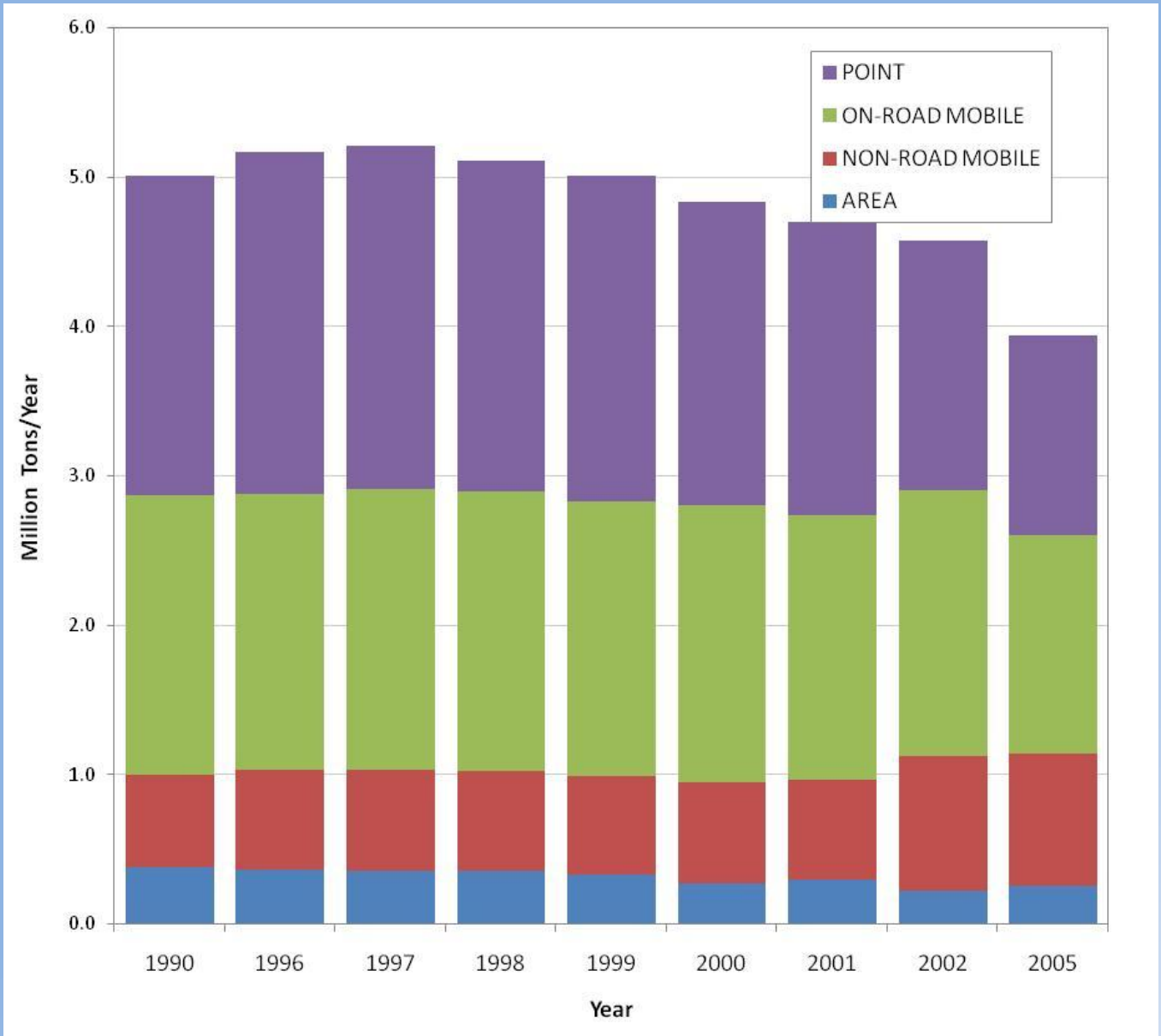
Source: 1990-2005 National Emissions Inventory

NH_3 Emissions by Source Category in the Southeast, 1990-2005



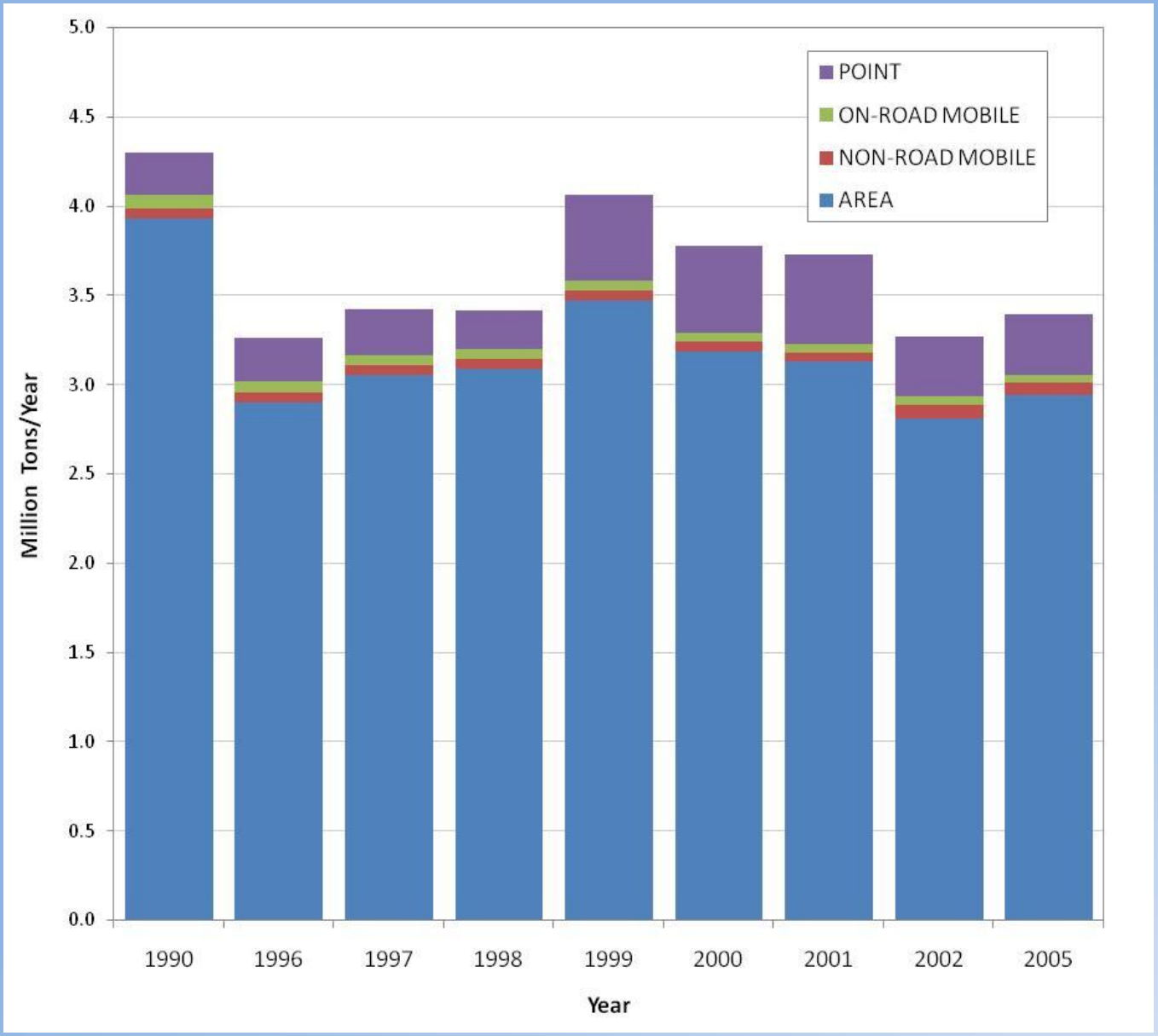
Source: 1990-2005 National Emissions Inventory

NO_x Emissions by Source Category in the Southeast, 1990-2005



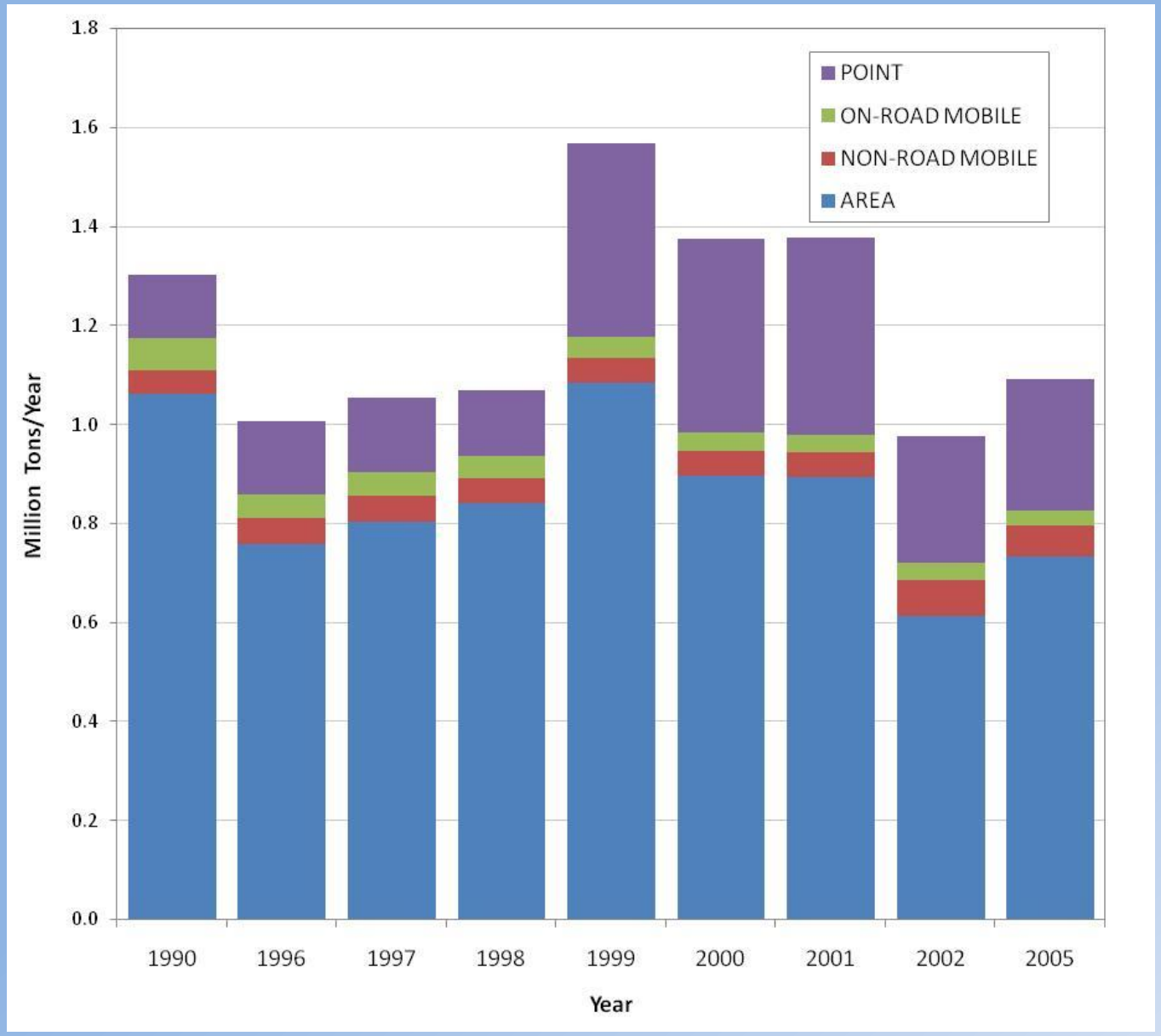
Source: 1990-2005 National Emissions Inventory

Primary PM_{10} Emissions by Source Category in the Southeast, 1990-2005



Source: 1990-2005 National Emissions Inventory

Primary $PM_{2.5}$ Emissions by Source Category in the Southeast, 1990-2005

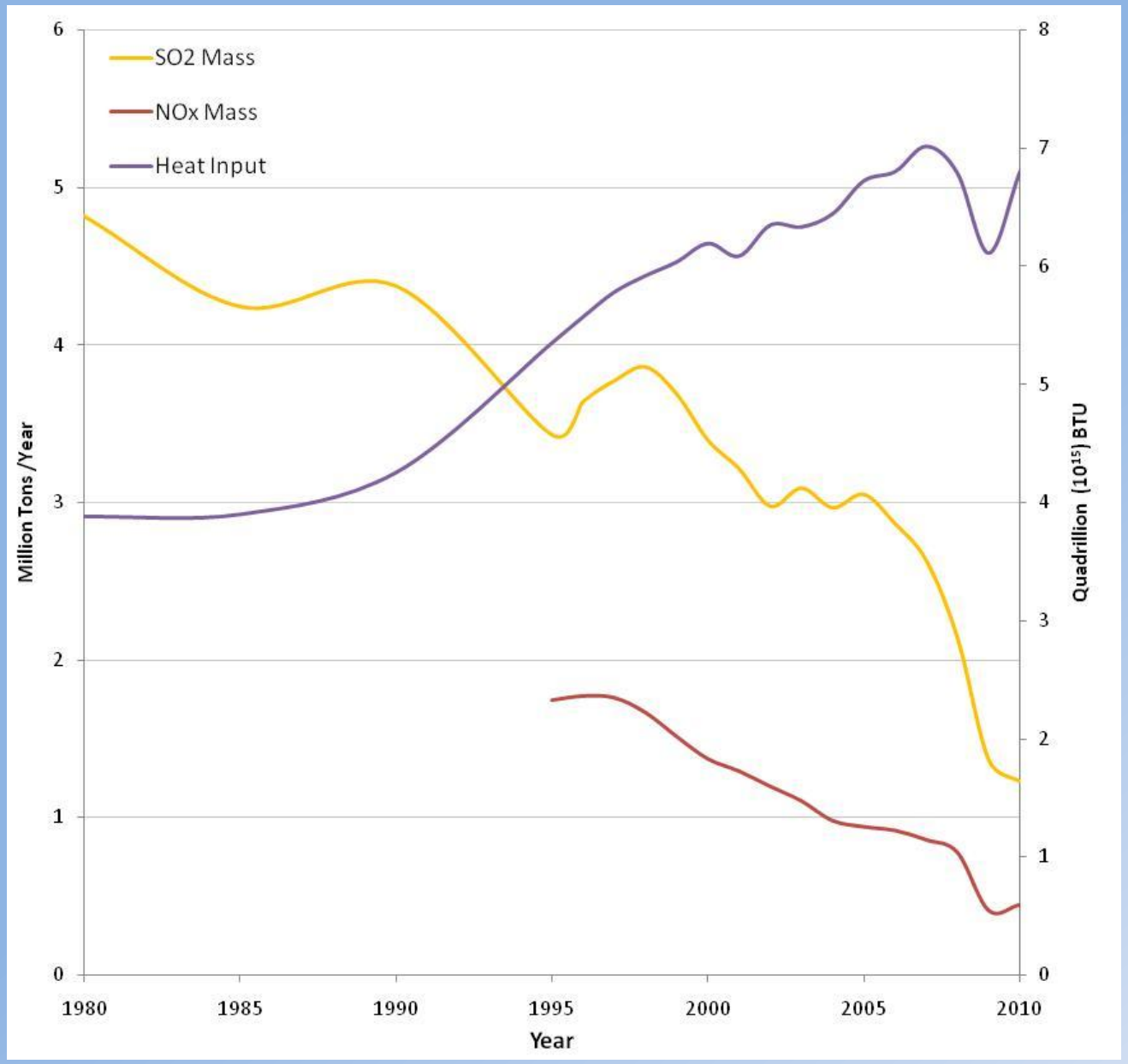


Source: 1990-2005 National Emissions Inventory

EPA Clean Air Markets Division Database

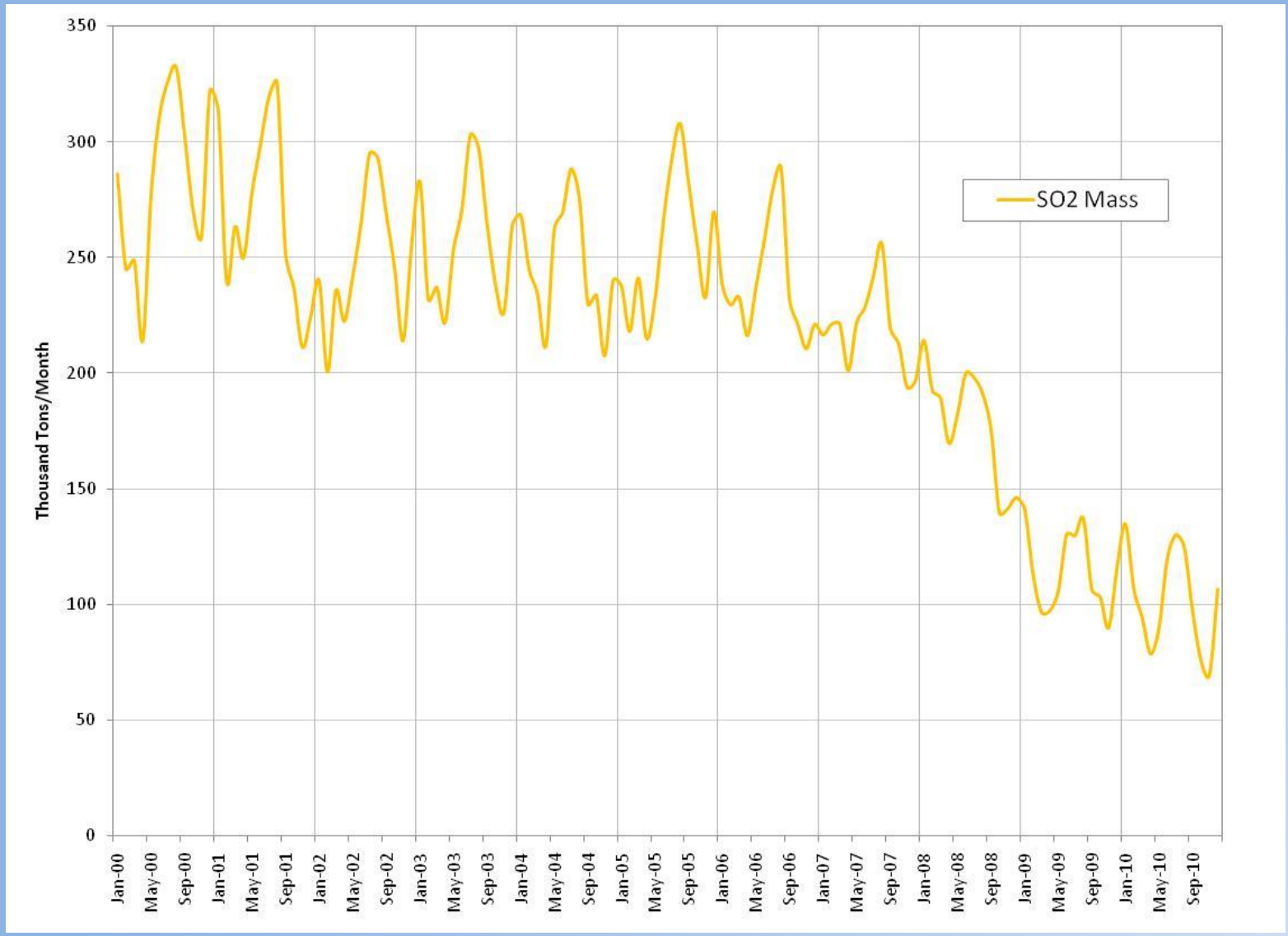
- Contains SO_2 and NO_x emissions data from units subject to:
  - ARP
  - NO_x SIP Call
  - CAIR
- Hourly data from continuous emissions monitoring systems (CEMS)
- More detailed and recent data than NEI
- Especially useful for SO_2
  - Dominated by point source emissions in NEI
- Online public access

Aggregate SO_2 and NO_x Emissions in the Southeast, 1980-2010



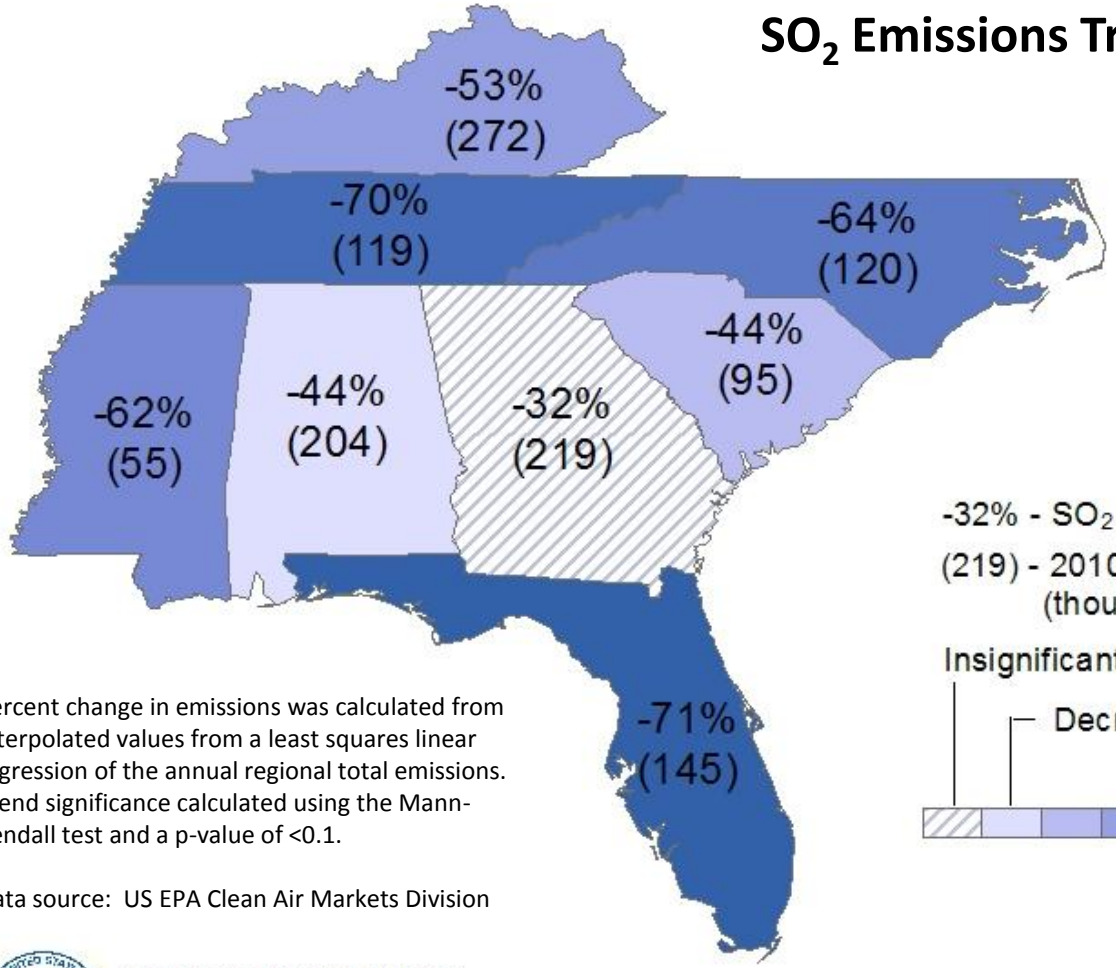
Source: EPA Clean Air Markets Division (CAMD) Data

Monthly Aggregate SO_2 Emissions in the Southeast, 2000-2010



Source: EPA CAMD Data

SO_2 Emissions Trends 2000-2010



-32% - SO_2 Percent Change

(219) - 2010 SO_2 Emissions (thousands of tons)

Insignificant Trend

Decreasing Trend

Percent change in emissions was calculated from interpolated values from a least squares linear regression of the annual regional total emissions. Trend significance calculated using the Mann-Kendall test and a p-value of <0.1.

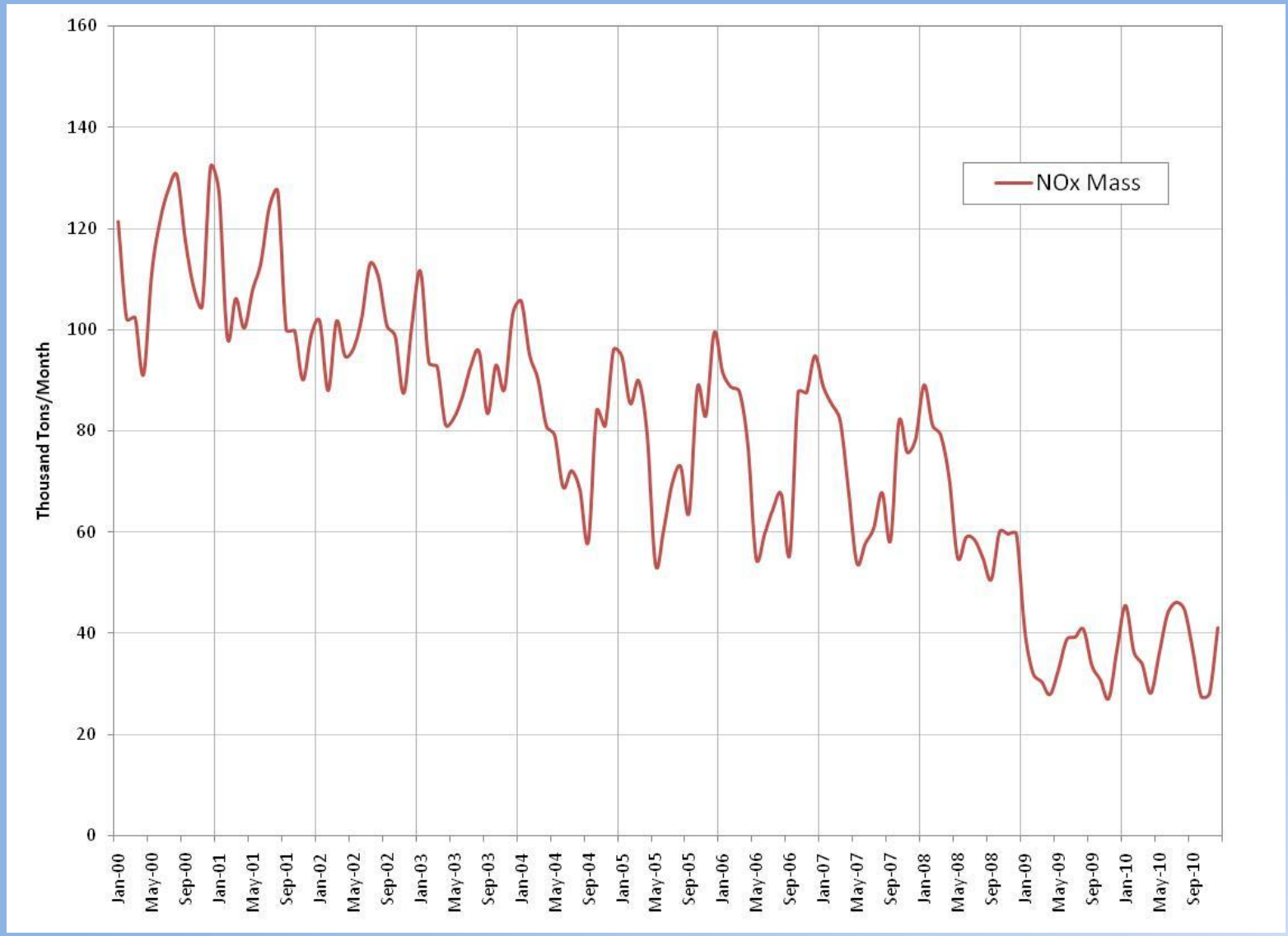
Data source: US EPA Clean Air Markets Division

Map created by Stacy Harder
U.S. EPA Region 4
April 19, 2011

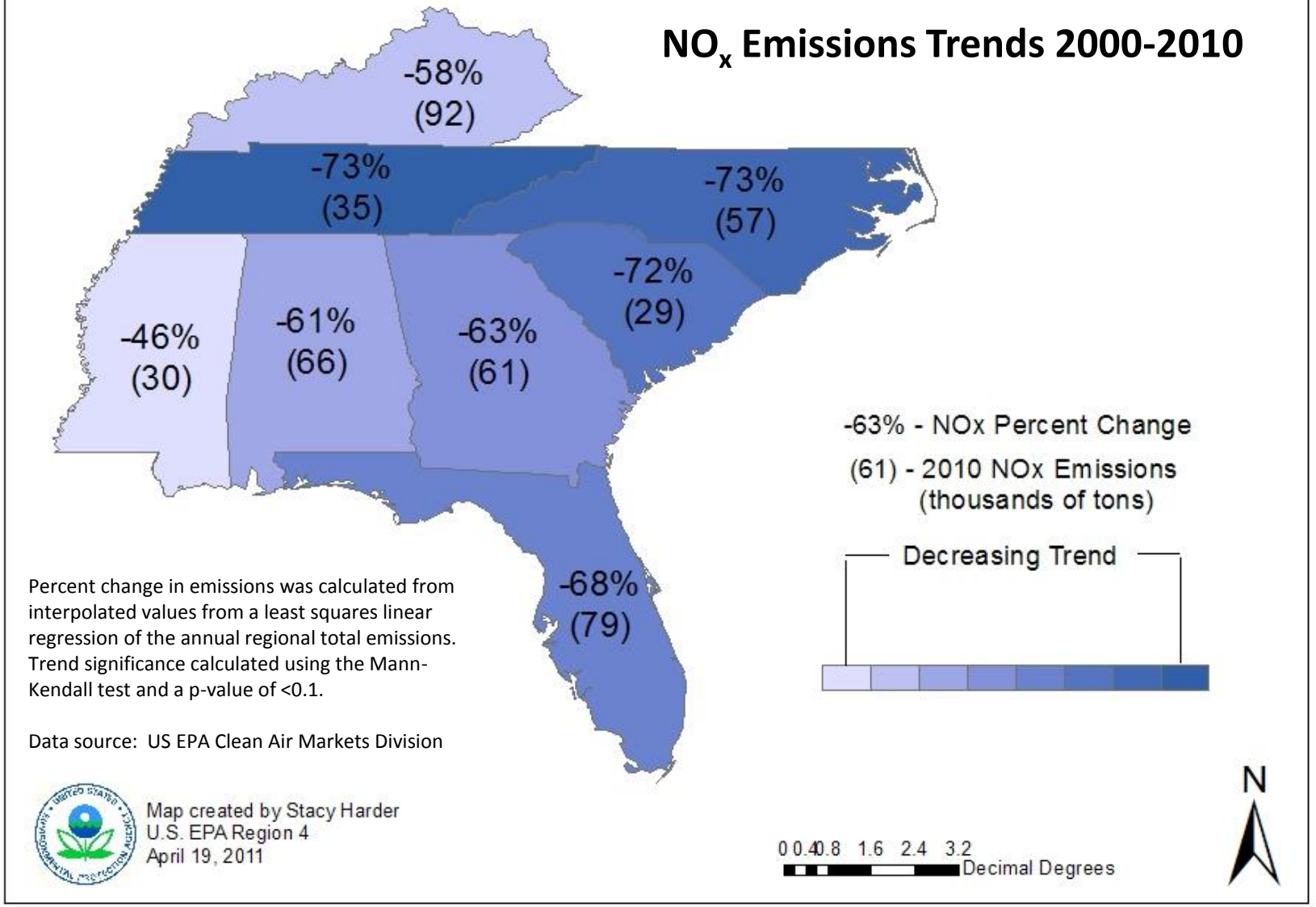
0 0.4 0.8 1.6 2.4 3.2
Decimal Degrees

N

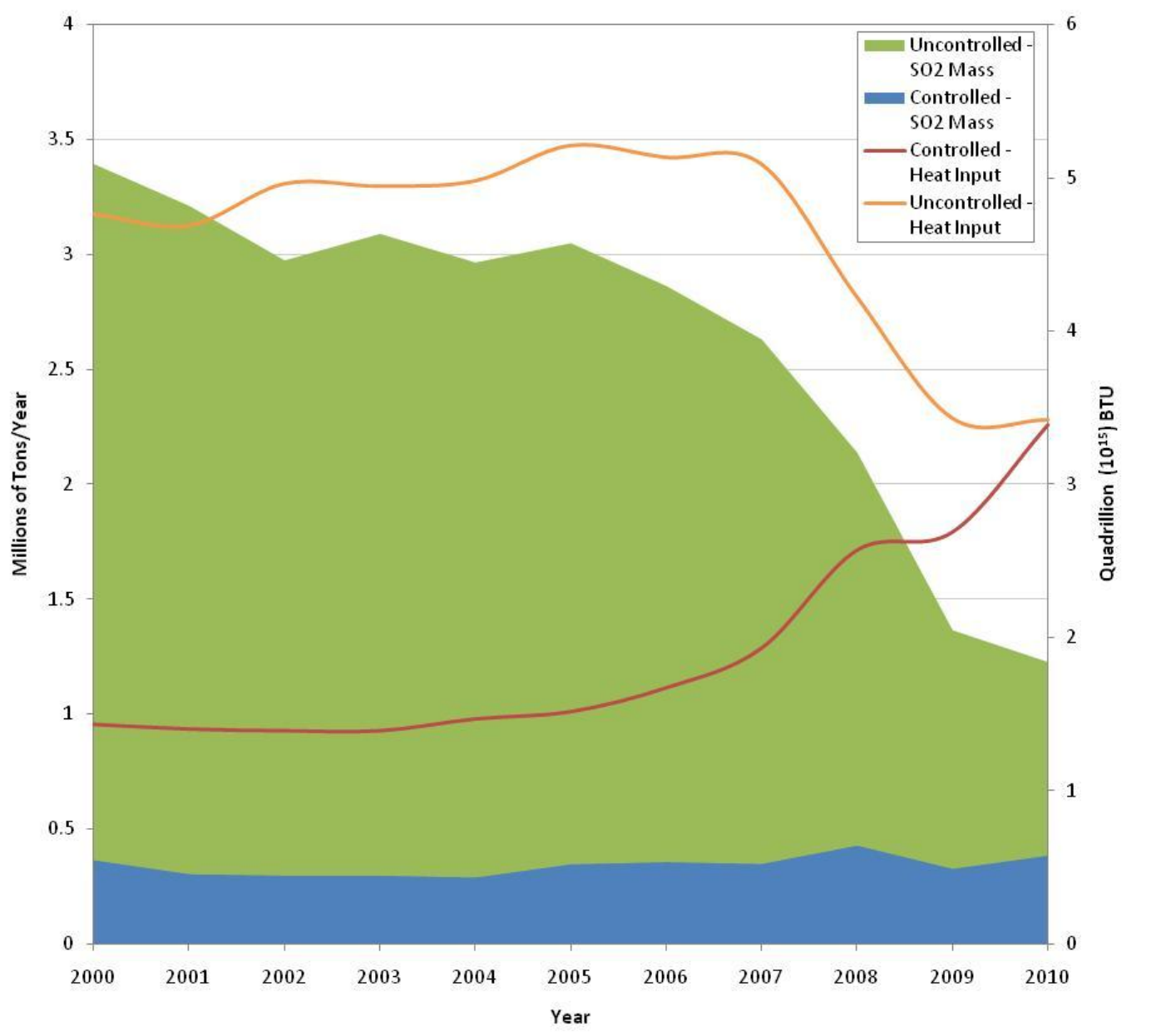
Monthly Aggregate NO_x Emissions in the Southeast, 2000-2010



Source: EPA CAMD Data

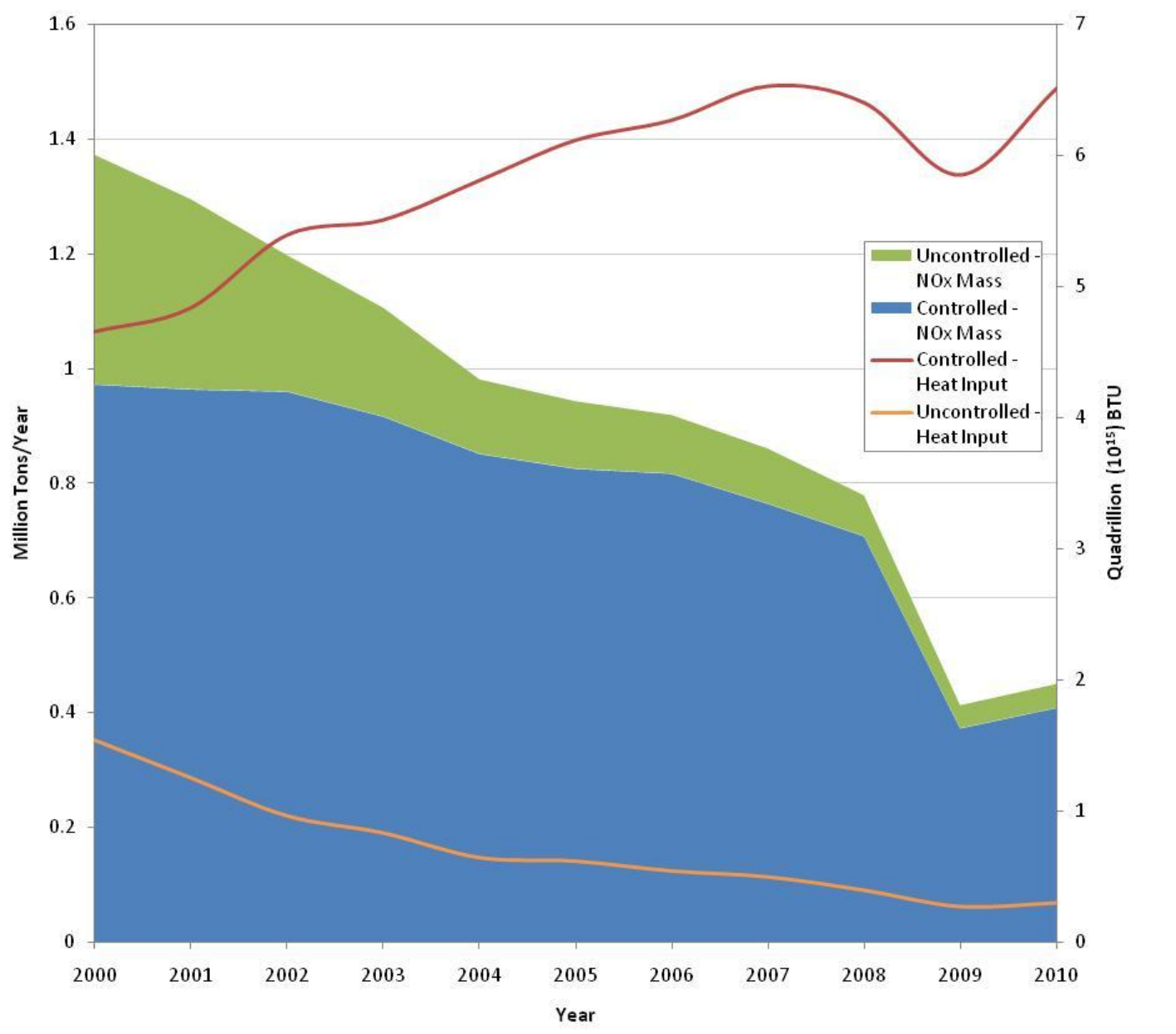

NOx Emissions Trends 2000-2010
-58%
(92)
-73%
(35)
-73%
(57)
-72%
(29)
-46%
(30)
-61%
(66)
-63%
(61)
-68%
(79)
-63% - NOx Percent Change
(61) - 2010 NOx Emissions
(thousands of tons)
Decreasing Trend
Percent change in emissions was calculated from interpolated values from a least squares linear regression of the annual regional total emissions. Trend significance calculated using the Mann-Kendall test and a p-value of <0.1.
Data source: US EPA Clean Air Markets Division
Map created by Stacy Harder
U.S. EPA Region 4
April 19, 2011
0 0.4 0.8 1.6 2.4 3.2
Decimal Degrees
N

Total SO_2 Emissions and Heat Input from Controlled and Uncontrolled Sources in the Southeast, 2000-2010

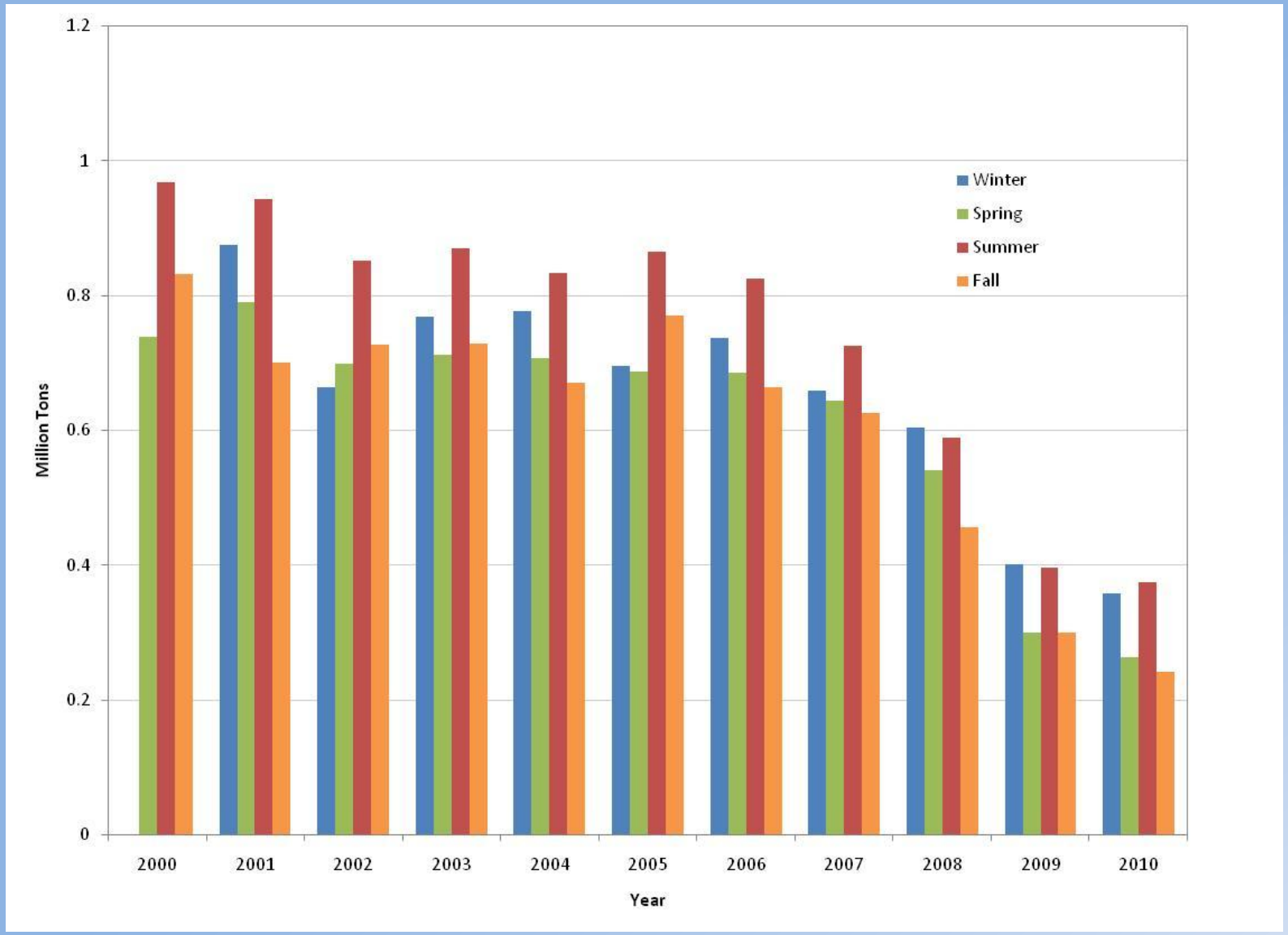


Source: EPA CAMD Data

Total NO_x Emissions and Heat Input from Controlled and Uncontrolled sources in the Southeast, 2000-2010

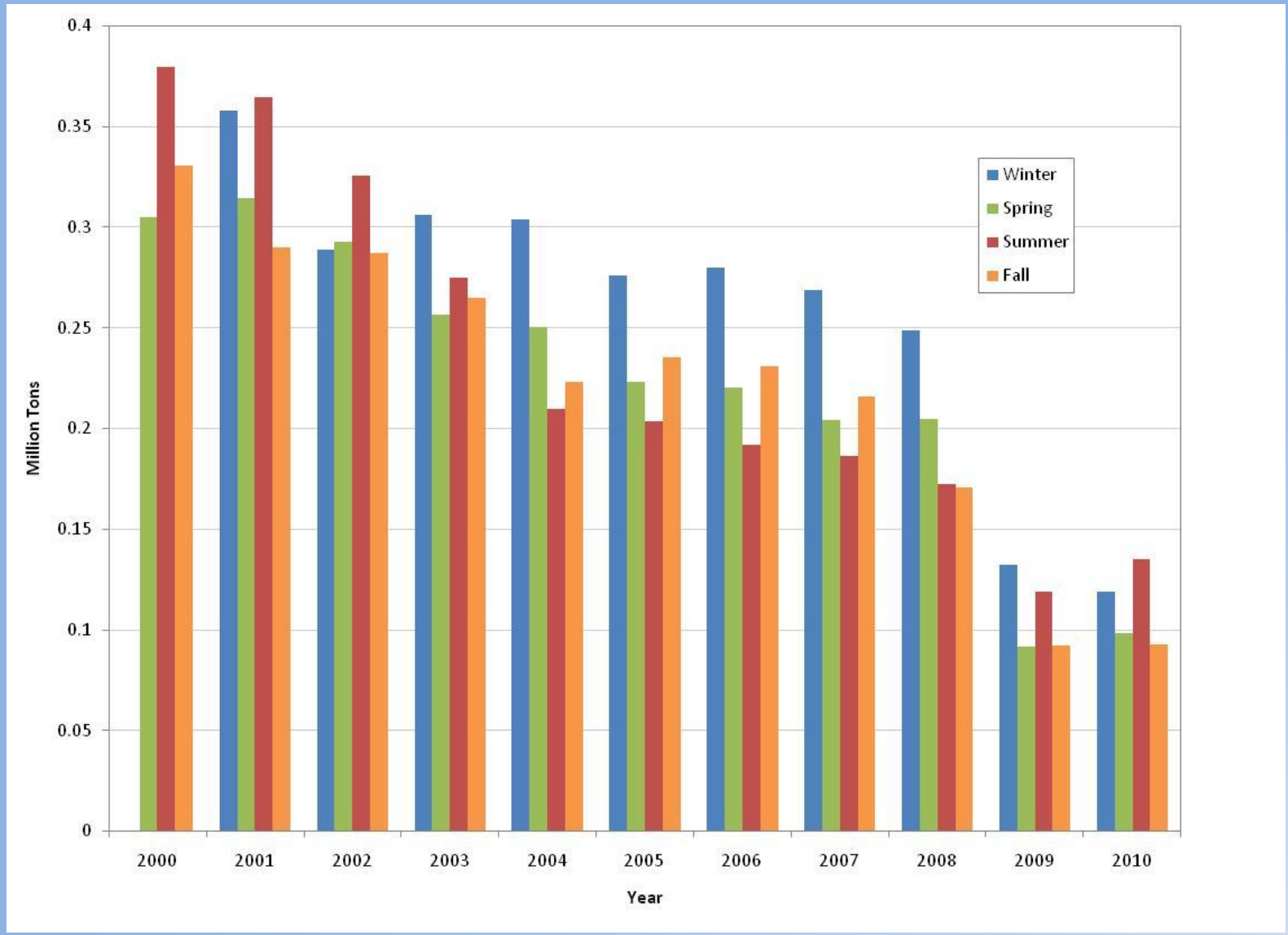


Seasonal Average Total SO_2 Emissions in the Southeast, 2000-2010



Source: EPA CAMD Data

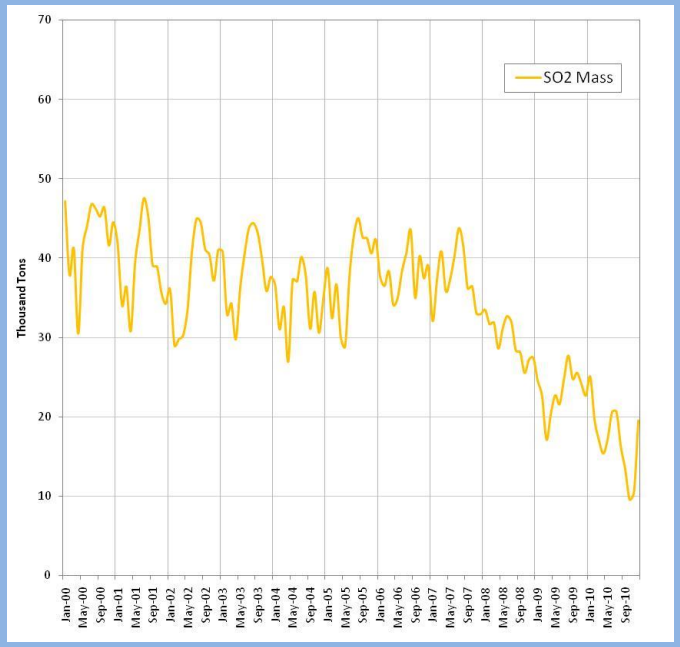
Seasonal Average Total NO_x Emissions in the Southeast, 2000-2010



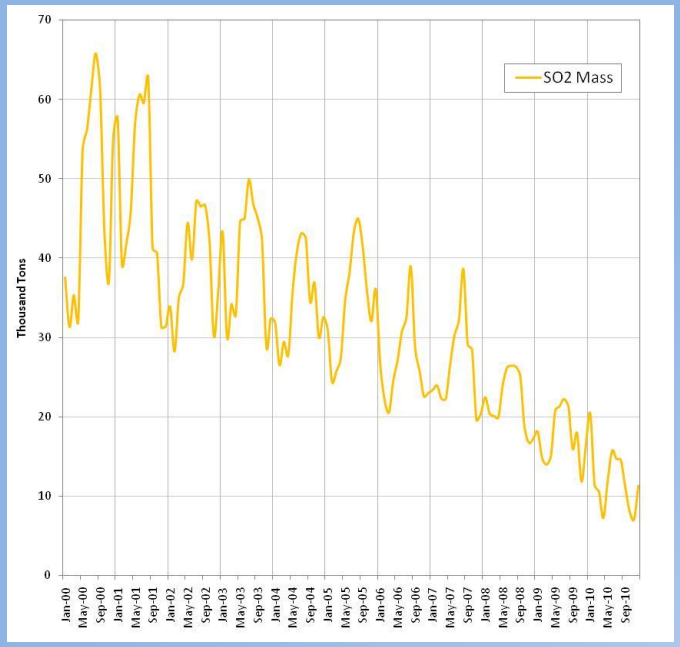
Source: EPA CAMD Data

Monthly Average Total SO_2 Emissions by State, 2000-2010

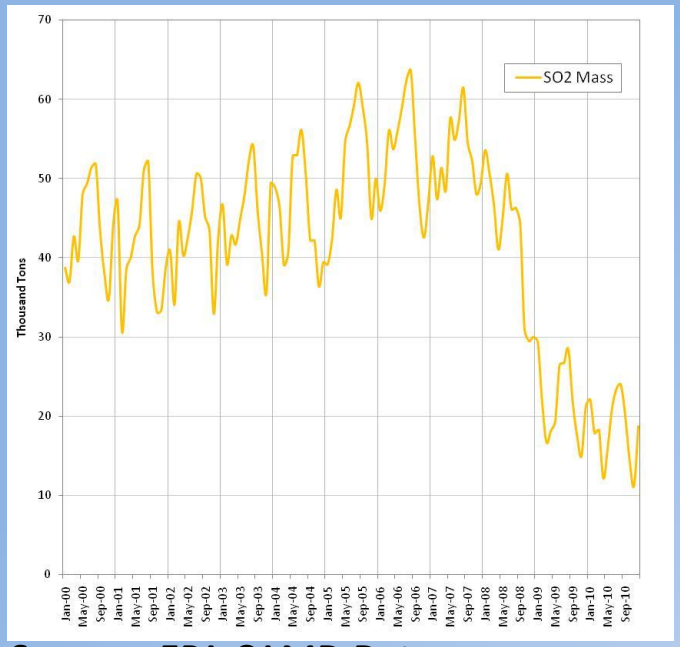
AL



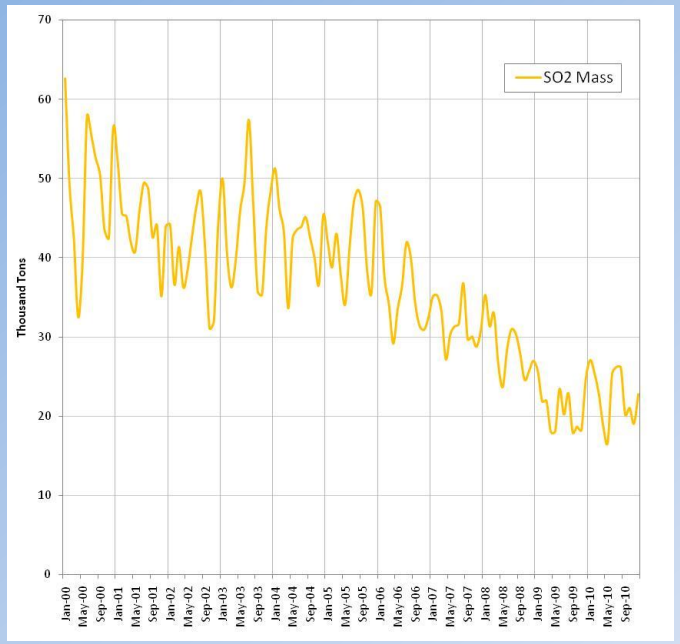
FL



GA



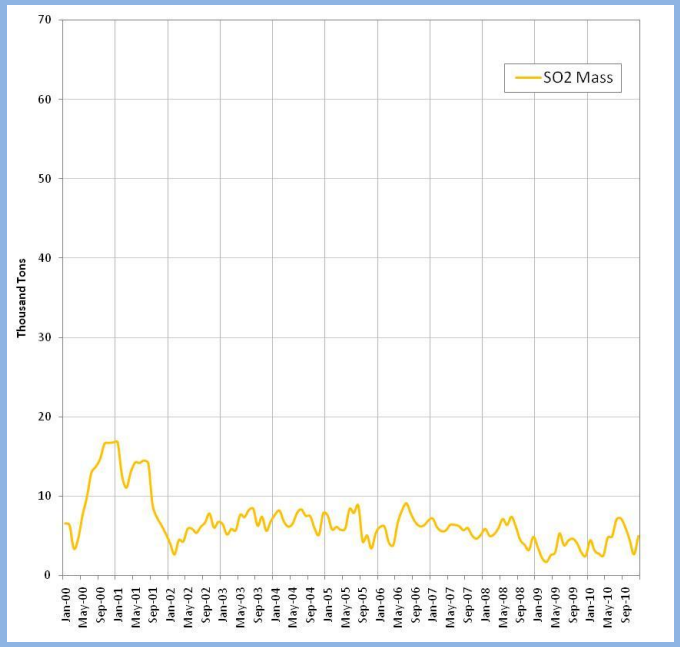
KY



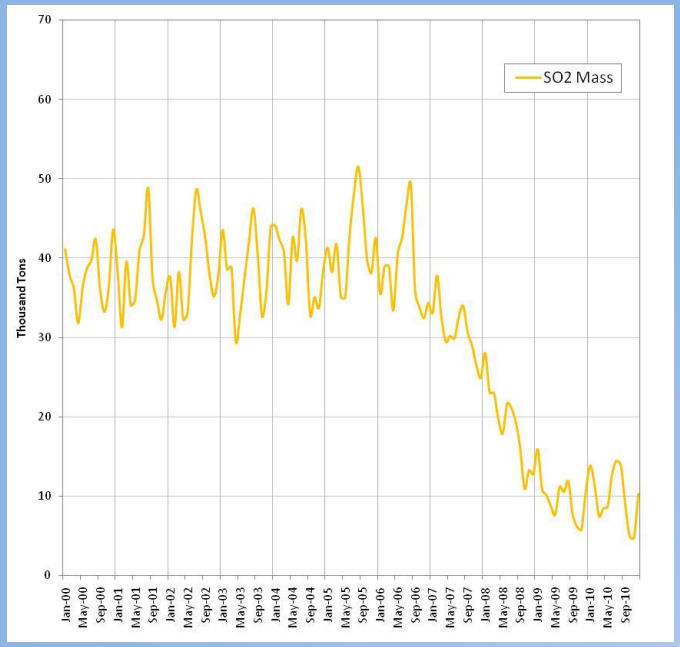
Source: EPA CAMD Data

Monthly Average Total SO_2 Emissions by State, 2000-2010

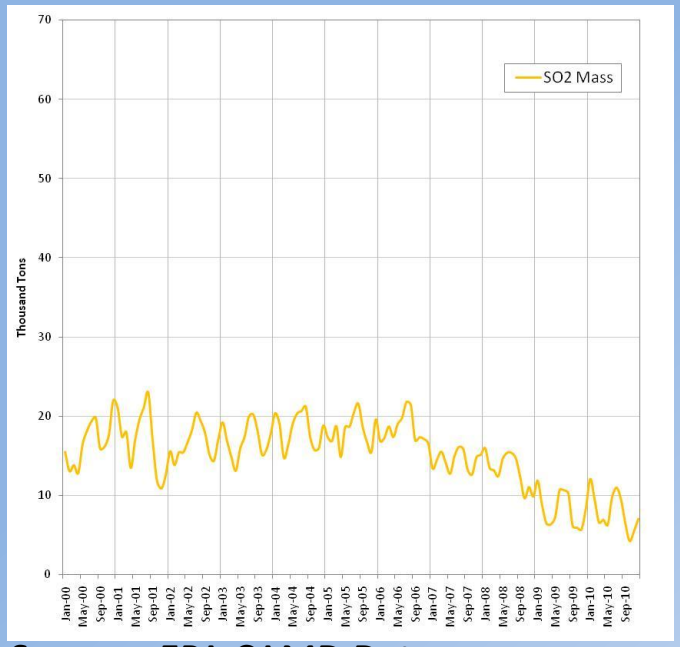
MS



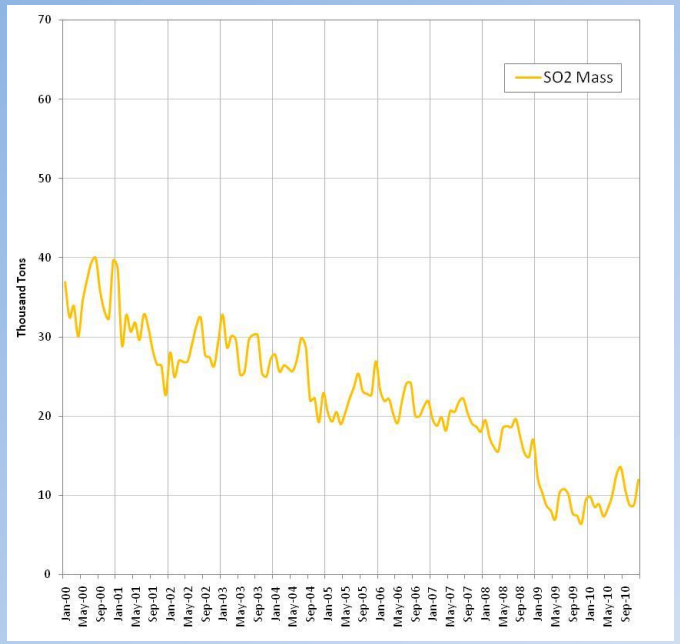
NC



SC



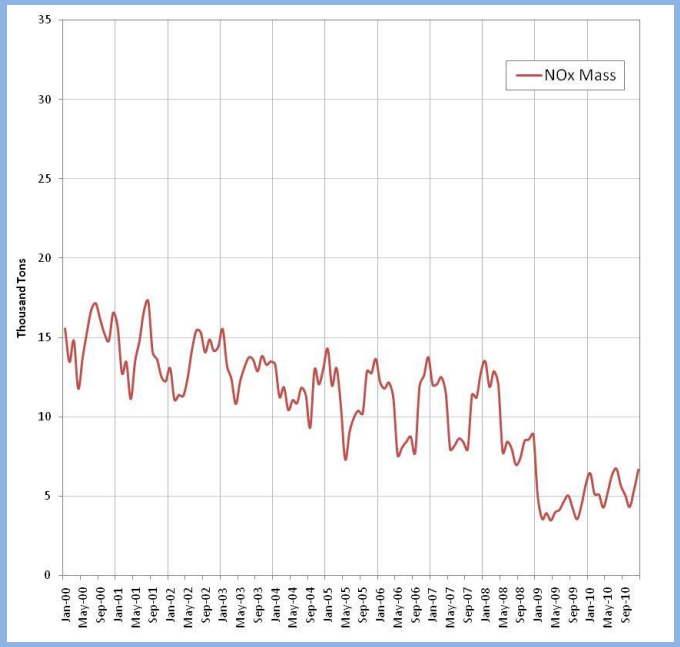
TN



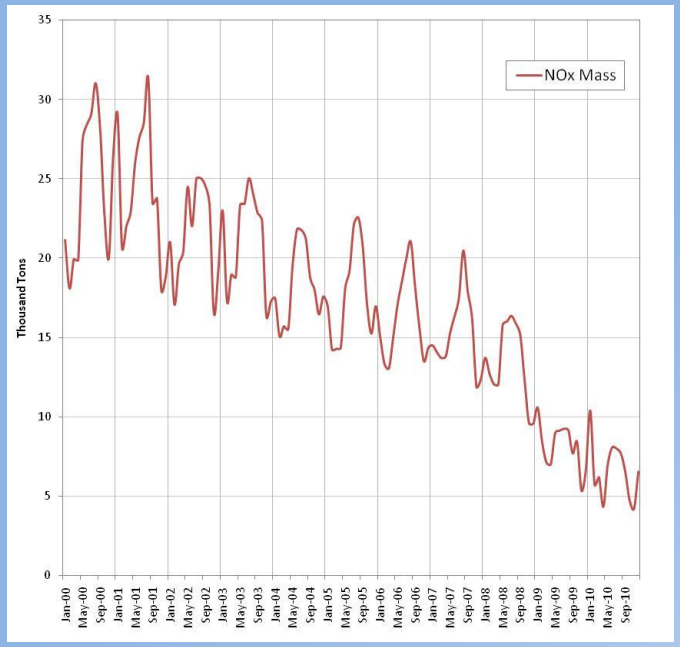
Source: EPA CAMD Data

Monthly Average Total NO_x Emissions by State, 2000-2010

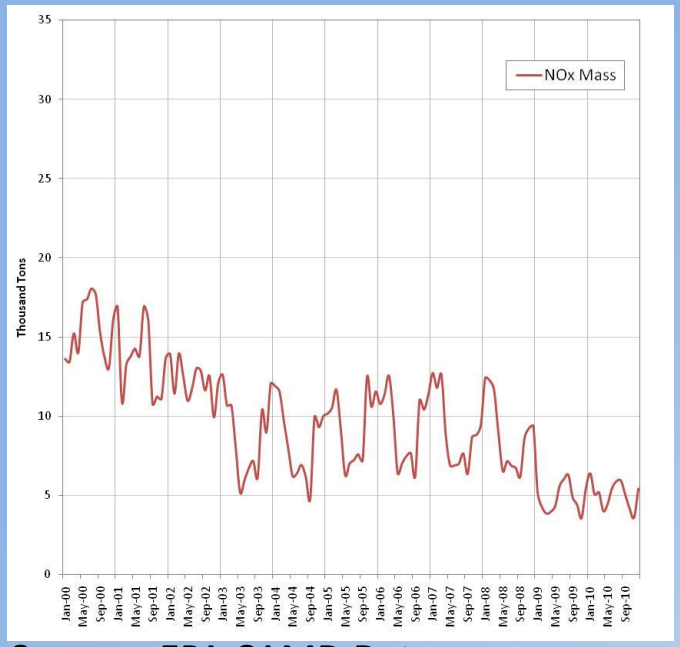
AL



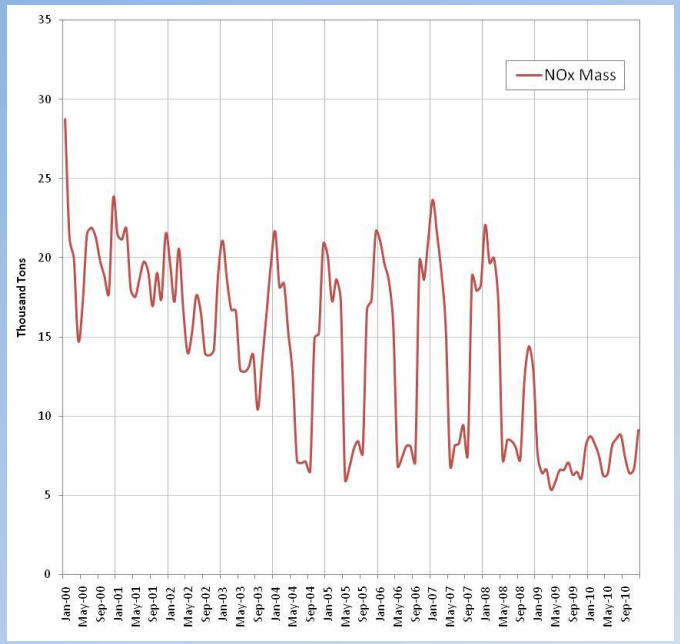
FL



GA



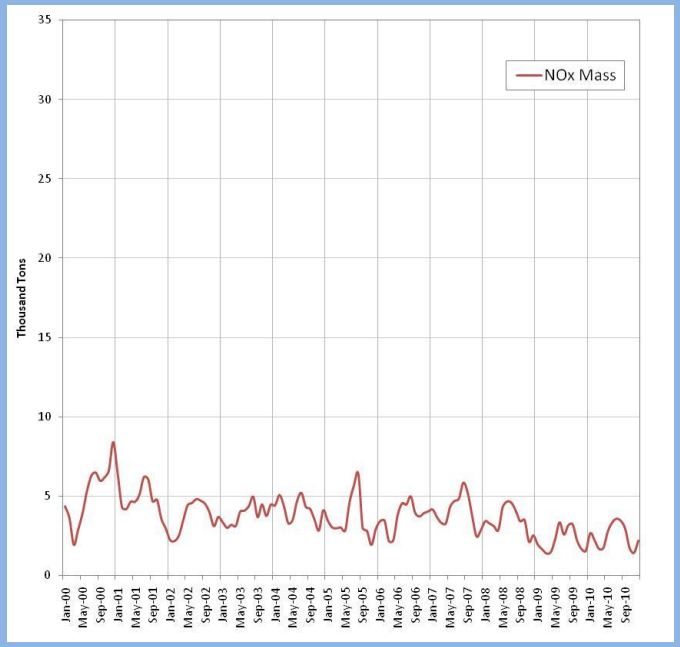
KY



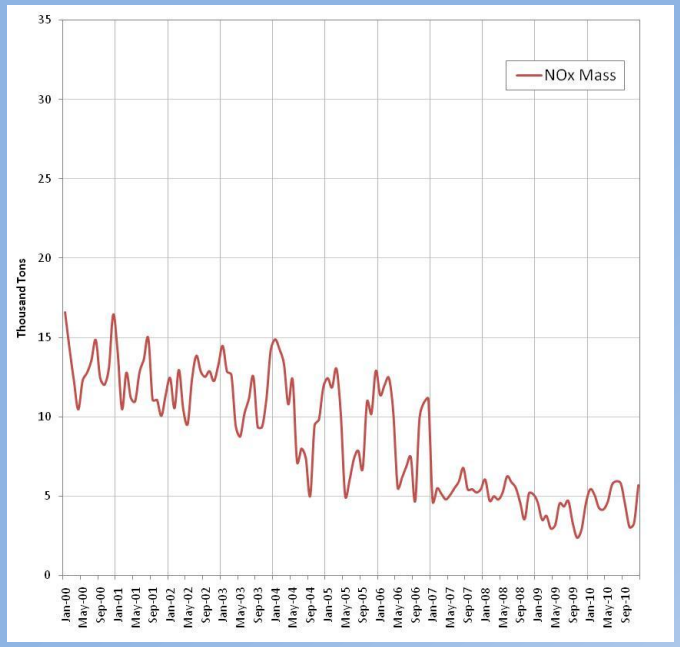
Source: EPA CAMD Data

Monthly Average Total NO_x Emissions by State, 2000-2010

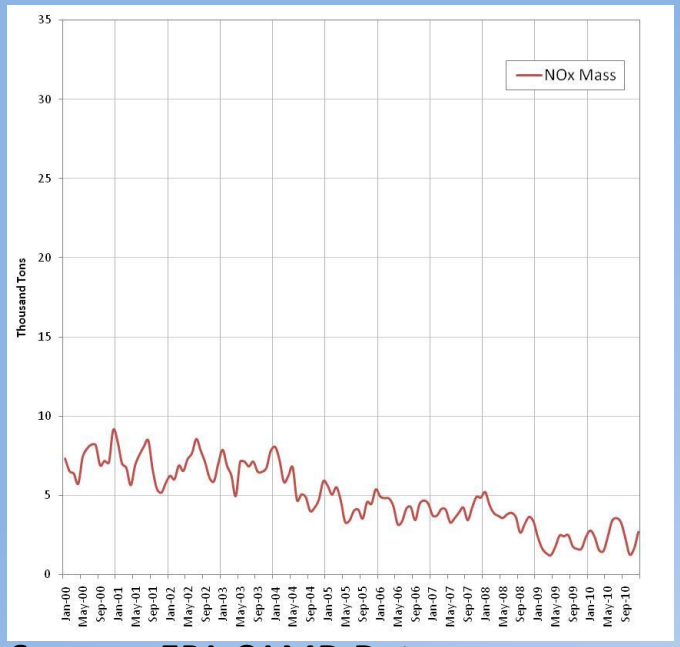
MS



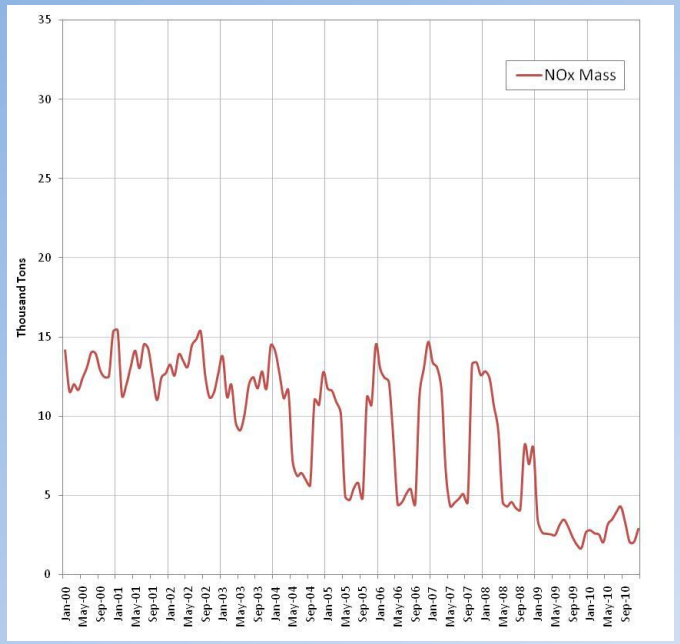
NC



SC



TN



Source: EPA CAMD Data

AMBIENT AIR QUALITY TRENDS

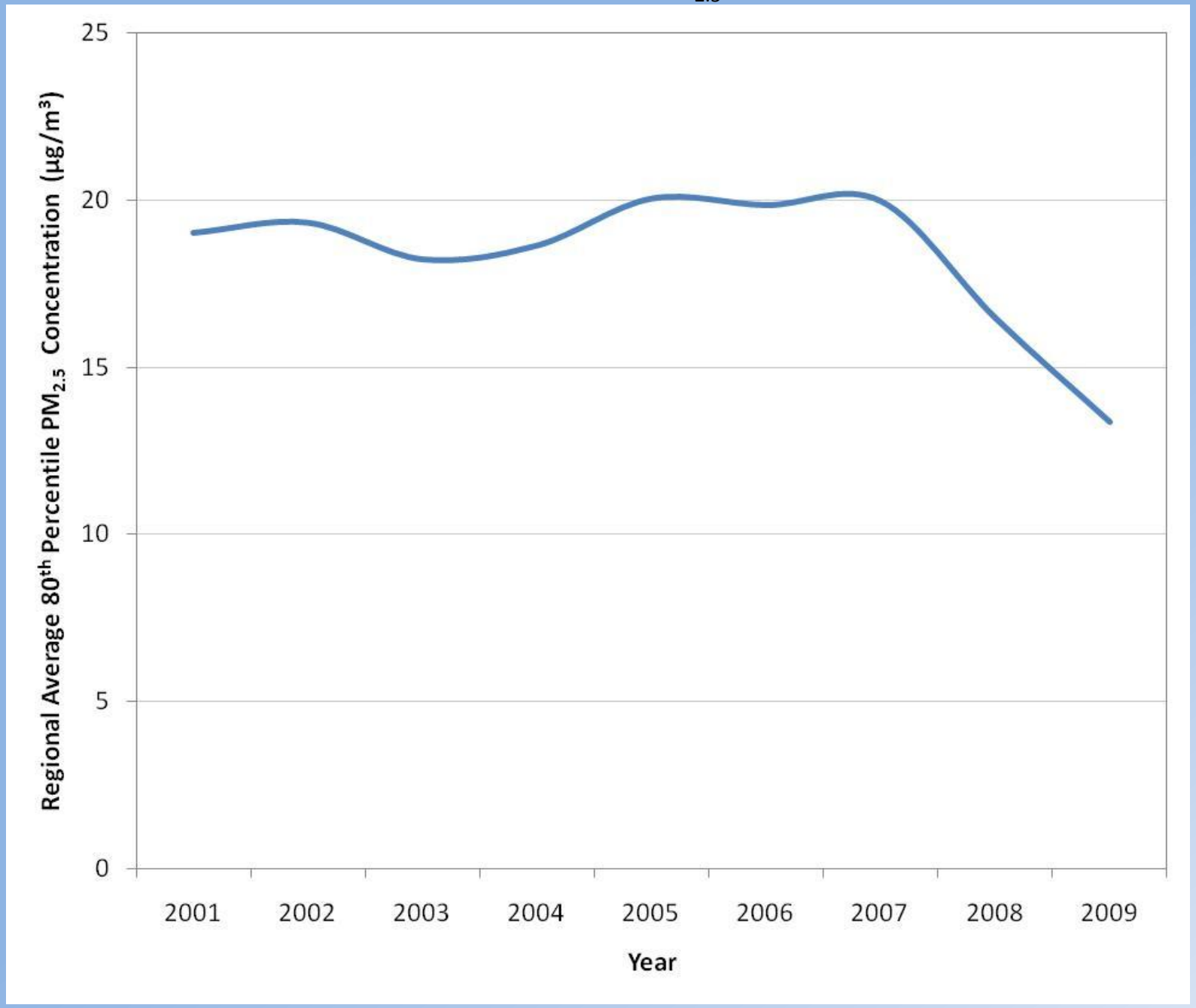
$PM_{2.5}$ and Speciated Aerosols

Monitoring Data Analysis

- Used most current and inclusive datasets available
- Analyzed data from
  - IMPROVE
  - Speciation Trends Network (STN)
  - Chemical Speciation Network (CSN)
- Graphical representation
- Statistical analysis of trends
  - Mann Kendall trend test

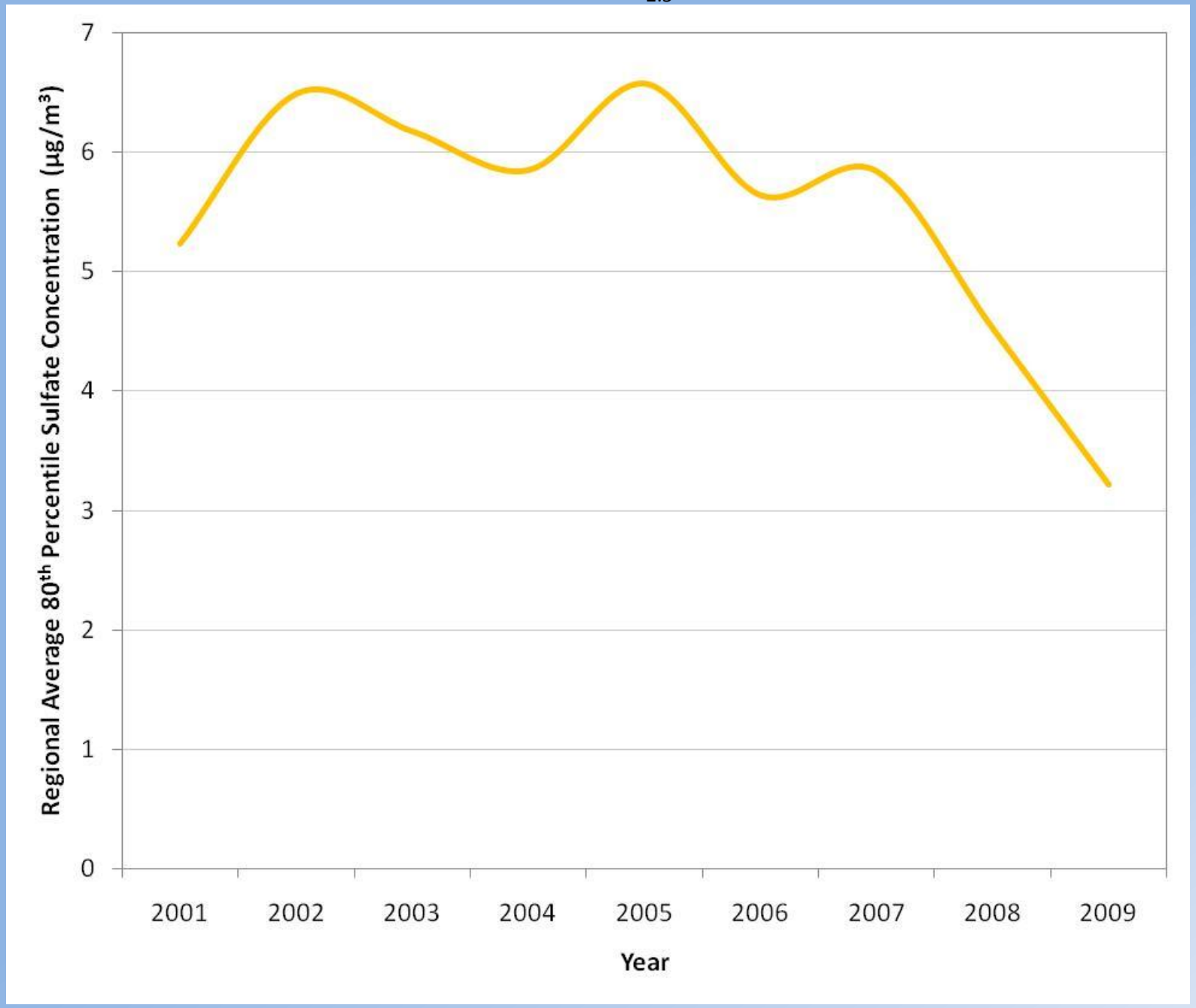
GRAPHICAL ANALYSIS OF TRENDS

Regional Average of 80th Percentile 24-hr $PM_{2.5}$ Concentrations, 2001-2009



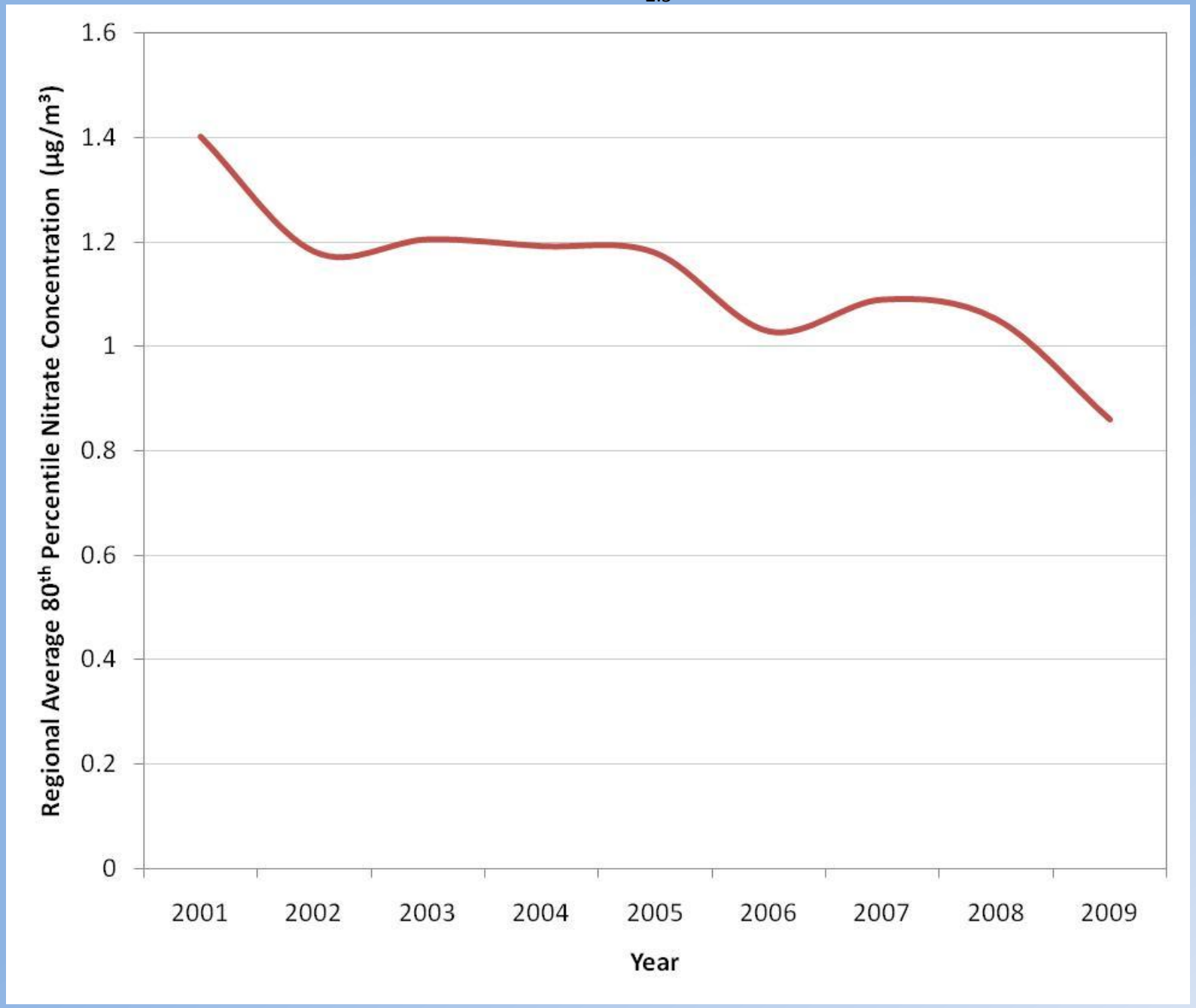
Source: EPA Air Quality System Database

Regional Average of 80th Percentile 24-hr $PM_{2.5}$ Sulfate Concentrations, 2001-2009



Source: EPA Air Quality System Database

Regional Average of 80th Percentile 24-hr $PM_{2.5}$ Nitrate Concentrations, 2001-2009

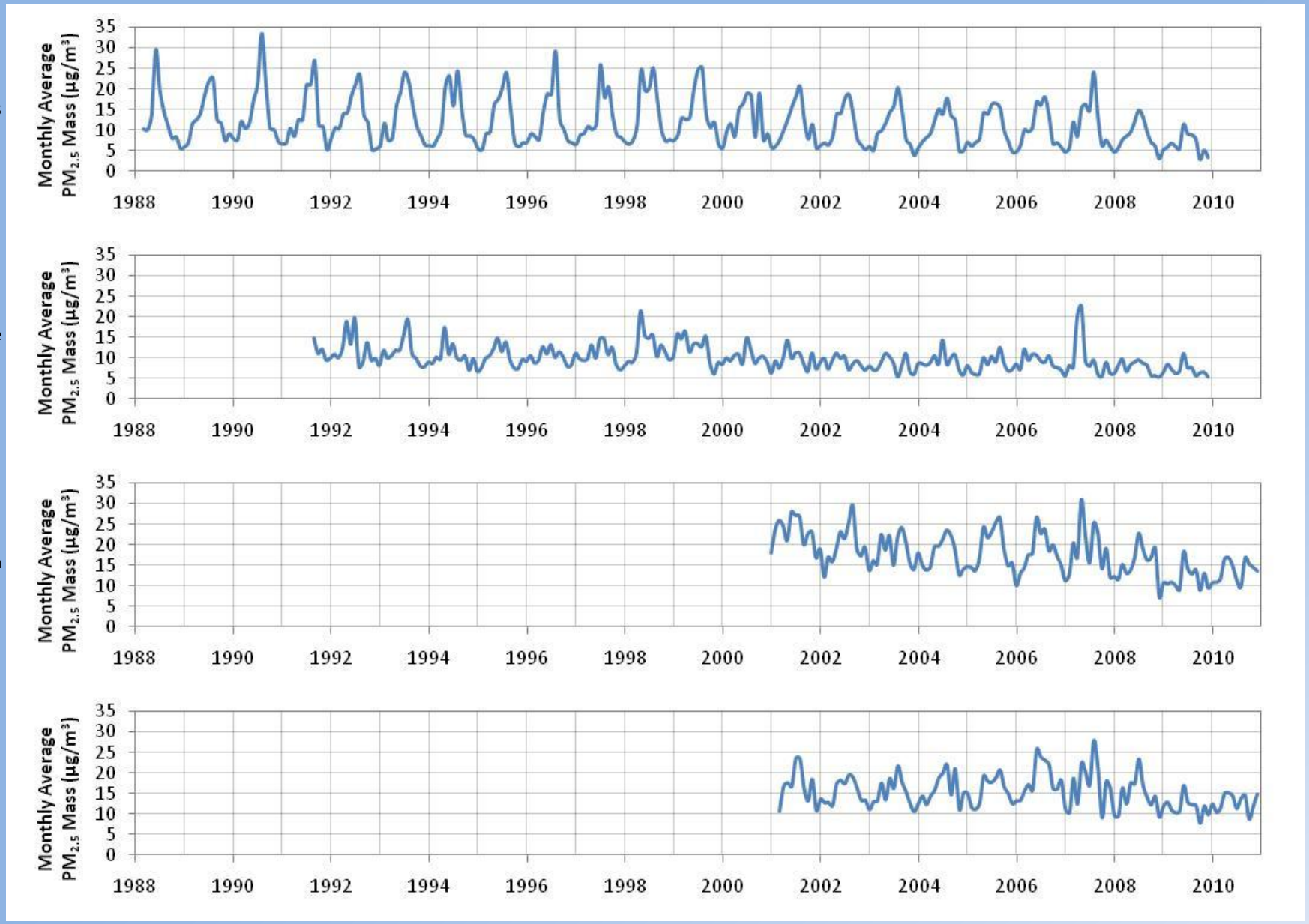


Source: EPA Air Quality System Database

Case Study: Trends at Individual Sites

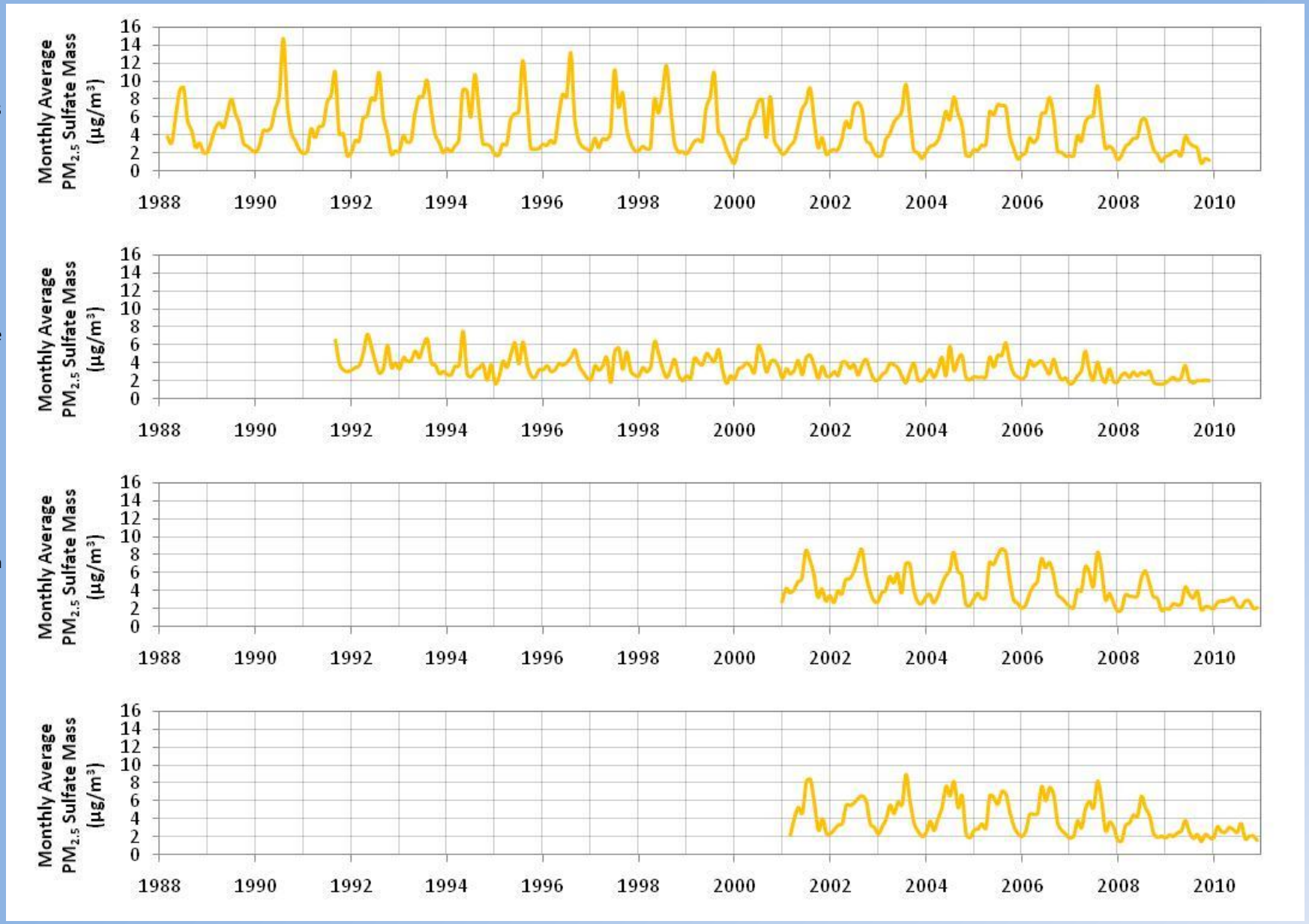
- Criteria for selecting sites:
  - Long data record
  - Geographically different
  - Urban vs. rural
- Selected four sites:
  - Great Smoky Mountains National Park, Look Rock (IMPROVE)
  - Okefenokee National Wildlife Refuge (IMPROVE)
  - Birmingham: North Birmingham (NCore)
  - Atlanta: South Dekalb (NCore)

Monthly Average $PM_{2.5}$ Concentration, 1988-2010



Source: EPA Air Quality System Database

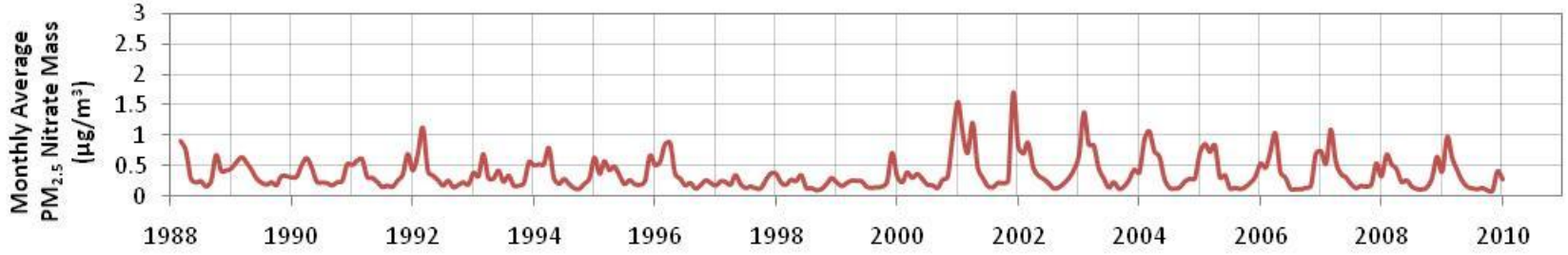
Monthly Average $PM_{2.5}$ Sulfate Concentration, 1988-2010



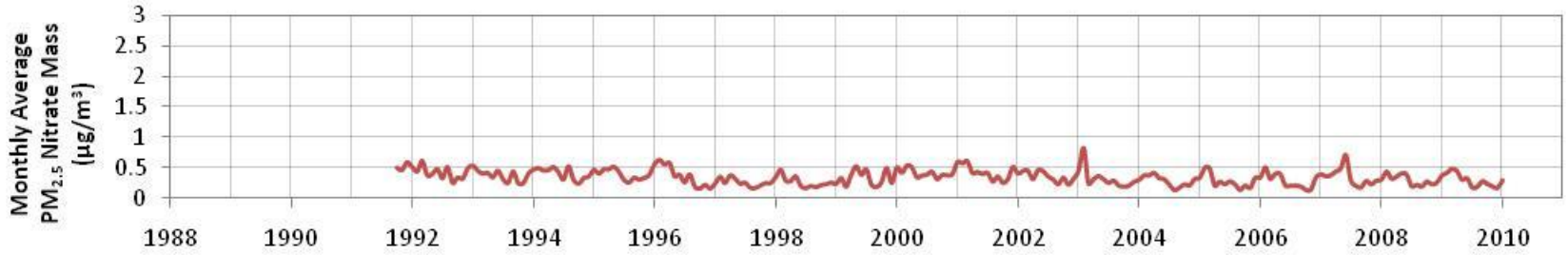
Source: EPA Air Quality System Database

Monthly Average $PM_{2.5}$ Nitrate Concentration, 1988-2010

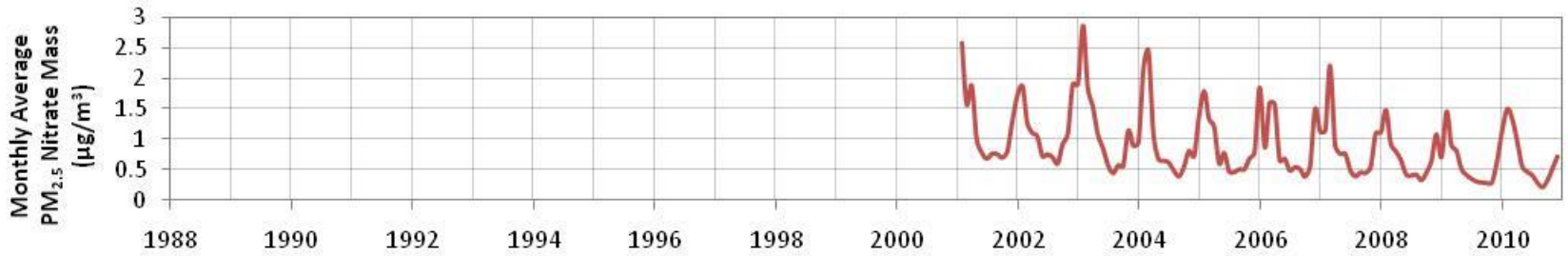
Great Smoky Mountains National Park



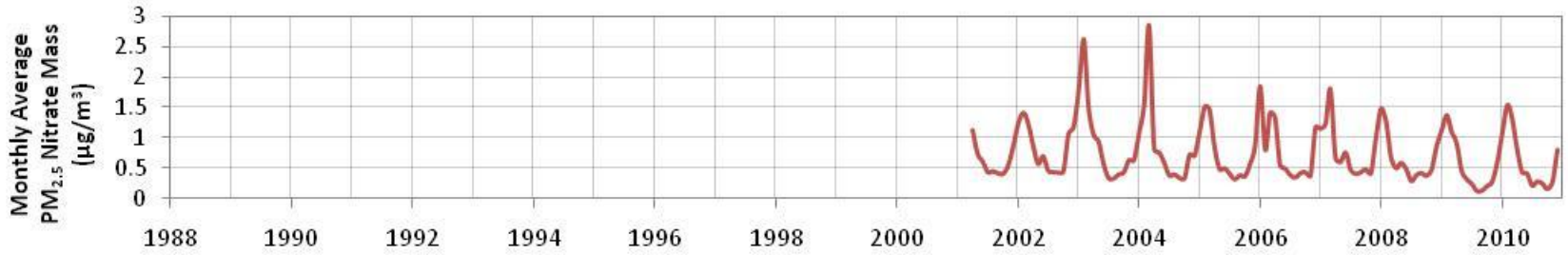
Okefenokee NWR



Birmingham



Atlanta



Source: EPA Air Quality System Database

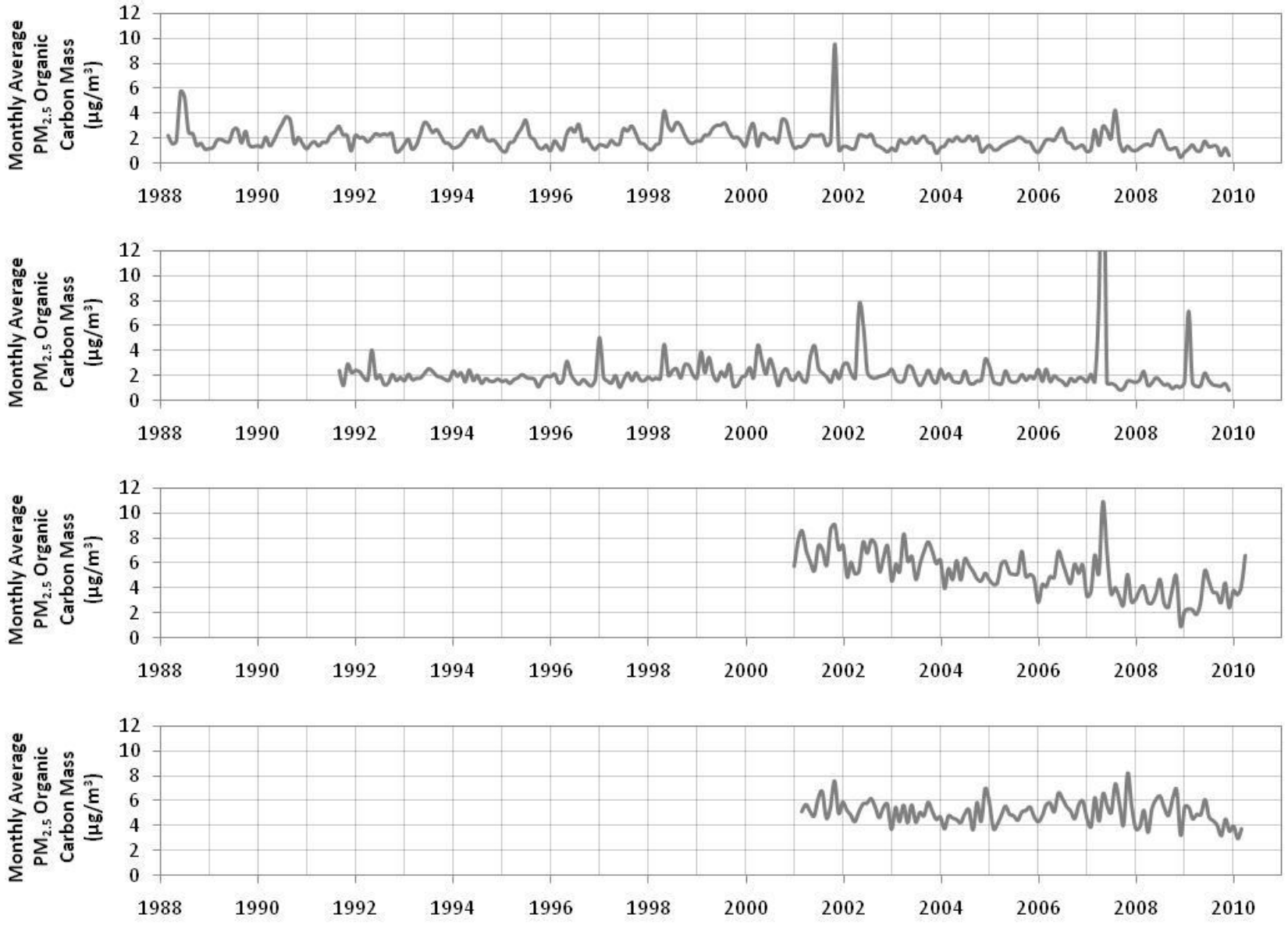
Monthly Average $PM_{2.5}$ Organic Carbon Concentration, 1988-2010

Great Smoky Mountains National Park

Okefenokee NWR

Birmingham

Atlanta



Source: EPA Air Quality System Database

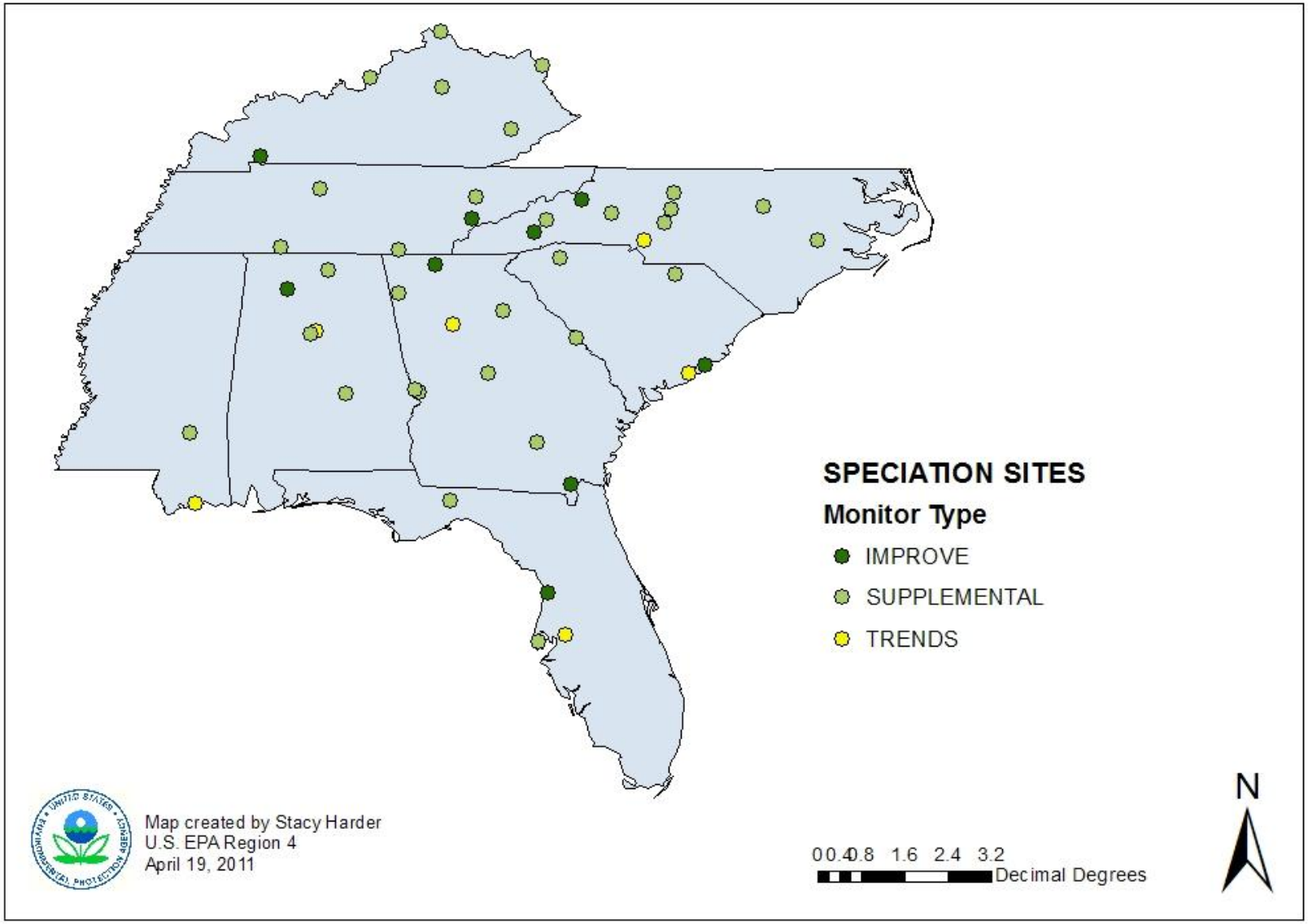
STATISTICAL ANALYSIS OF TRENDS

Mann Kendall Trend Test Briefly

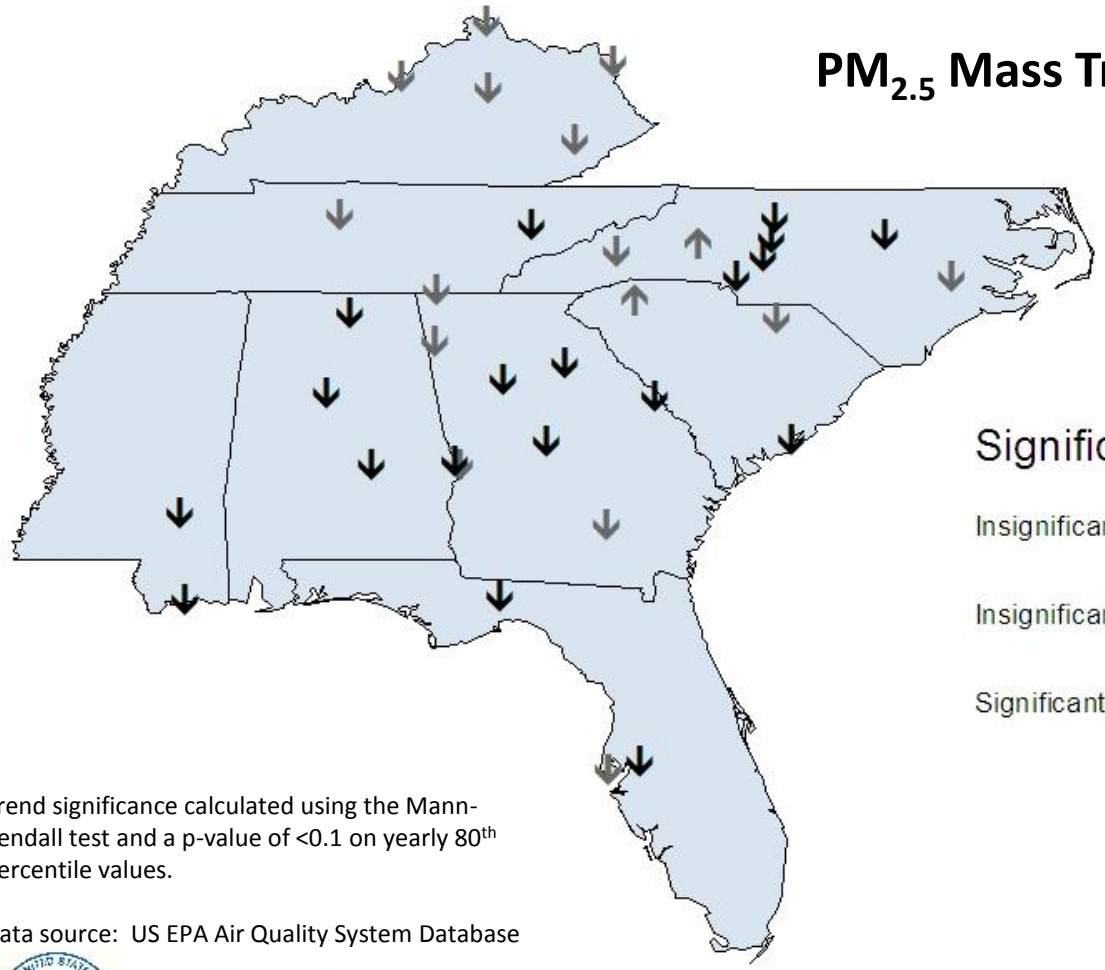
- Mann Kendall only detects for the presence (or not) of a significant trends – The magnitude or shape of an upward or downward trend is not considered
- Periodic data sets, such as a seasonal time series, can give this test problems – can be mitigated by grouping the data into seasons before using the Mann Kendall test

Trend Analysis – Site Criteria

- Use data from as many Region 4 sites as possible
- Filtered the monitors in order to exclude
  - No data prior to 2006
    - Short time periods of operation
  - No data after January 1, 2008
    - Shutdown of the monitor more than 3 years ago
  - Monitor types defined as “Special Purpose”, “Non-Regulatory”, and “Other”
    - due to overlap with other monitor types at the same site
  - Hourly data
- 47 Region 4 sites met the criteria


SPECIATION SITES
Monitor Type
IMPROVE
SUPPLEMENTAL
TRENDS
Map created by Stacy Harder
U.S. EPA Region 4
April 19, 2011
0 0.4 0.8 1.6 2.4 3.2
Decimal Degrees
N

$PM_{2.5}$ Mass Trends



Significance

Insignificant Upward

Insignificant Downward

Significant Downward

Trend significance calculated using the Mann-Kendall test and a p-value of <0.1 on yearly 80th percentile values.

Data source: US EPA Air Quality System Database

Map created by Stacy Harder
U.S. EPA Region 4
April 19, 2011

0 0.5 1 2 3 4
Decimal Degrees

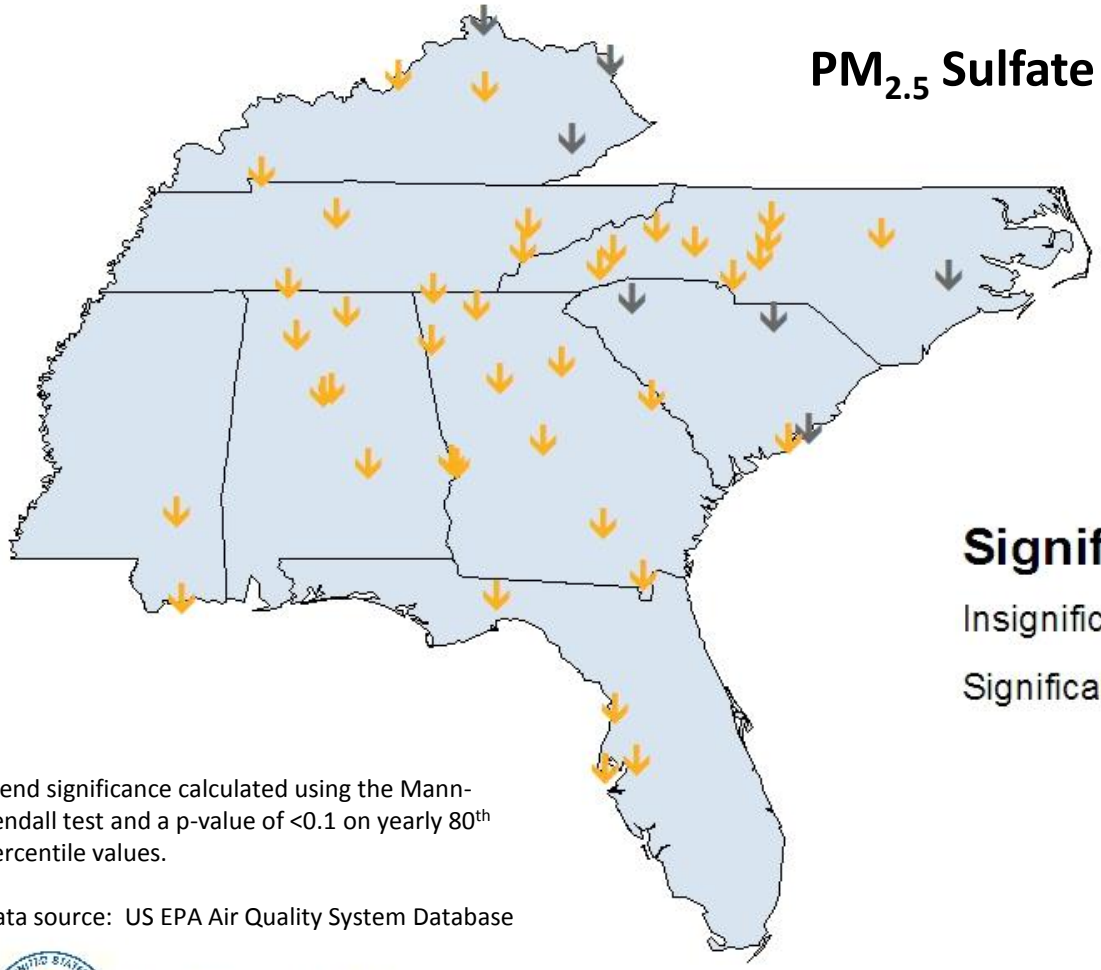
N

Seasonal and Monthly $PM_{2.5}$ Mass Trends – 47 Region 4 sites

	Month/Season	Not Significant Downward	Not Significant Upward	Significant Downward	Significant Upward
$PM_{2.5}$ Mass	**Overall**	**6%**	**2%**	**91%**	
	Winter	**17%**	**6%**	**77%**	
	Spring	**19%**	**11%**	**70%**	
	Summer	**13%**	**9%**	**79%**	
	Fall	**9%**		**91%**	
	January	32%	17%	49%	2%
	February	38%	9%	51%	2%
	March	43%	21%	32%	4%
	April	51%	6%	43%	
	May	28%	11%	62%	
	June	36%	23%	38%	2%
	July	26%	4%	70%	
	August	19%	13%	66%	2%
	September	19%	2%	79%	
	October	19%		81%	
	November	34%	28%	28%	11%
	December	47%	21%	30%	2%

Trend analysis performed on average monthly values.

$PM_{2.5}$ Sulfate Trends



Significance

Insignificant Downward

Significant Downward

Trend significance calculated using the Mann-Kendall test and a p-value of <0.1 on yearly 80th percentile values.

Data source: US EPA Air Quality System Database

Map created by Stacy Harder
U.S. EPA Region 4
April 19, 2011

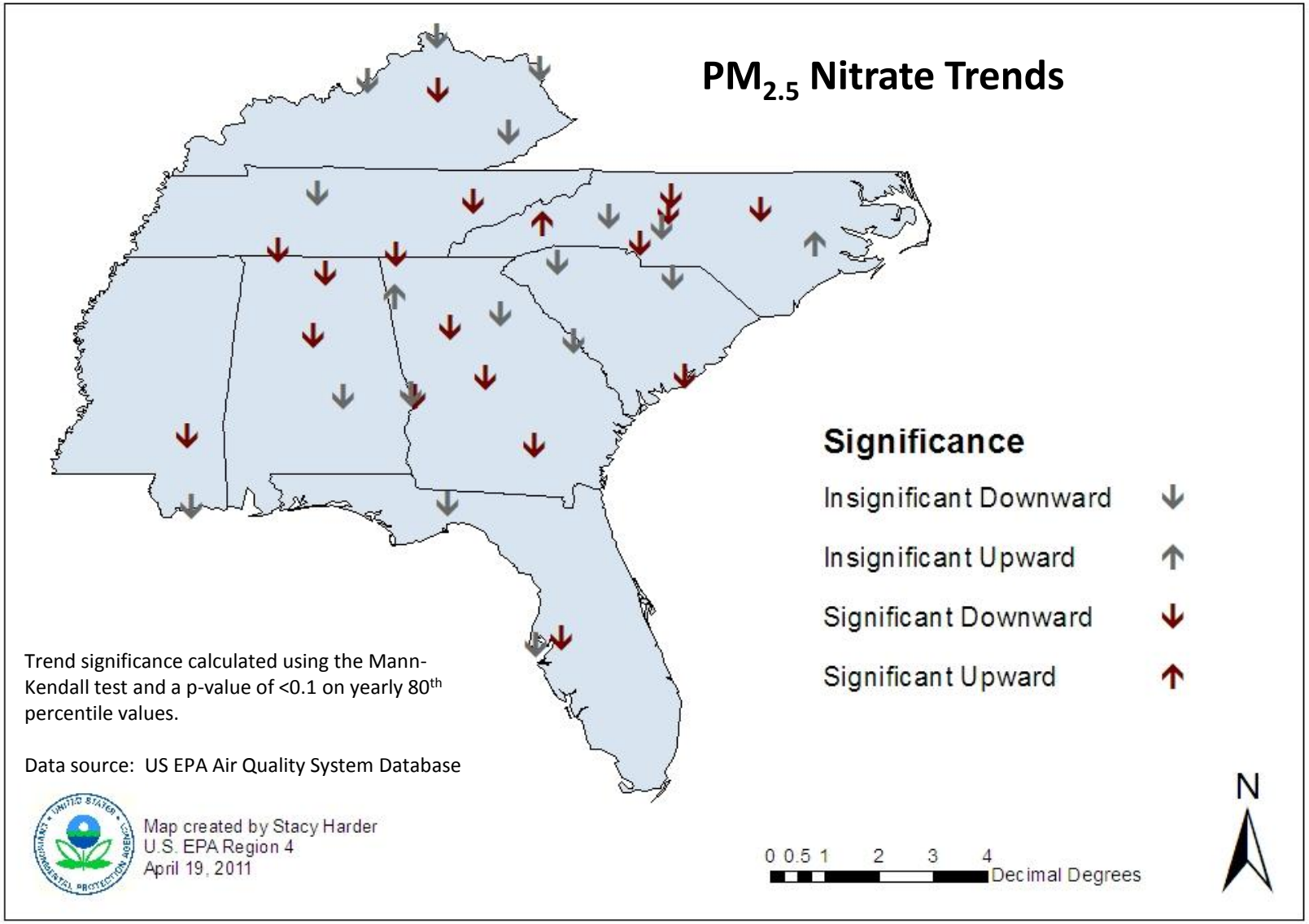
0 0.5 1 2 3 4
Decimal Degrees

N

Seasonal and Monthly $PM_{2.5}$ Sulfate Trends – 47 Region 4 sites

	Month/Season	Not Significant Downward	Not Significant Upward	Significant Downward	Significant Upward
$PM_{2.5}$ Sulfate	**Overall**			**100%**	
	Winter	**19%**	**9%**	**72%**	
	Spring	**9%**	**2%**	**89%**	
	Summer	**6%**	**4%**	**89%**	
	Fall	**6%**		**94%**	
	January	26%	6%	66%	2%
	February	36%	4%	60%	
	March	38%	6%	55%	
	April	19%	2%	79%	
	May	11%	4%	85%	
	June	21%	17%	62%	
	July	4%	4%	91%	
	August	15%	4%	81%	
	September	11%	2%	87%	
	October	11%		89%	
	November	21%	6%	72%	
	December	34%	17%	45%	4%

Trend analysis performed on average monthly values.


PM2.5 Nitrate Trends
Significance
Insignificant Downward
Insignificant Upward
Significant Downward
Significant Upward
Trend significance calculated using the Mann-Kendall test and a p-value of <0.1 on yearly 80th percentile values.
Data source: US EPA Air Quality System Database
Map created by Stacy Harder
U.S. EPA Region 4
April 19, 2011
0 0.5 1 2 3 4
Decimal Degrees
N

Seasonal and Monthly $PM_{2.5}$ Nitrate Trends – 47 Region 4 sites

	Month/Season	Not Significant Downward	Not Significant Upward	Significant Downward	Significant Upward
$PM_{2.5}$ Nitrate	**Overall**		**2%**	**98%**	
	Winter	**23%**	**13%**	**60%**	**4%**
	Spring	**13%**	**6%**	**81%**	
	Summer			**100%**	
	Fall	**21%**	**4%**	**74%**	
	January	45%	30%	17%	9%
	February	32%	17%	47%	4%
	March	47%	15%	34%	4%
	April	34%	9%	57%	
	May	21%	2%	77%	
	June	15%		85%	
	July	9%	4%	87%	
	August	17%		83%	
	September	30%	4%	66%	
	October	17%		83%	
	November	51%	15%	32%	2%
	December	40%	21%	38%	

Trend analysis performed on average monthly values.

Upward Trends

- Many of the not statistically significant upward trends can be explained by only having data through mid 2008
  - These data sets miss the recent drop in SO_2 and NO_x emissions
- Only two statistically significant upward trends
  - Both for winter nitrate near the Great Smokey Mountains National Park – Look Rock, TN and Blue Ridge Parkway, NC

$PM_{2.5}$ Mass Upward Trends

Month or Season	Number	Mann-Kendall Statistic	Standard Deviation	p-value	Trend
Spring	88	166	277.5	0.2748	not significant upward
Summer	92	286	296.5	0.1674	not significant upward
Spring	104	209	356.0	0.2786	not significant upward
Summer	89	225	282.2	0.2126	not significant upward
Summer	100	394	335.8	0.1203	not significant upward
Spring	104	310	356.0	0.1920	not significant upward
Spring	**103**	**283**	**350.9**	**0.2100**	**not significant upward**
Winter	**229**	**609**	**1158.9**	**0.2996**	**not significant upward**
Winter	**250**	**1589**	**1321.5**	**0.1146**	**not significant upward**

Start Date	Last Date	Total Data	State	County	City
08-Jan-02	07-Mar-08	351	North Carolina	Lenoir	Kinston
08-Jan-02	07-Mar-08	351	North Carolina	Lenoir	Kinston
03-Nov-01	30-May-08	390	Kentucky	Perry	Hazard
03-Nov-01	30-May-08	390	Kentucky	Perry	Hazard
21-Nov-01	27-Sep-08	423	South Carolina	Greenville	Taylors
20-Jan-02	26-Dec-08	410	Kentucky	Jefferson	Louisville
03-Mar-02	**08-Mar-09**	**407**	**Georgia**	**Floyd**	**Rome**
08-Mar-01	**30-Dec-09**	**988**	**Kentucky**	**Trigg**	**Not in a city**
01-Apr-00	**30-Dec-09**	**1072**	**North Carolina**	**Avery**	**Not in a city**

Trend analysis performed on average monthly values.

$PM_{2.5}$ Sulfate Upward Trends

Month or Season	Number	Mann-Kendall Statistic	Standard Deviation	p-value	Trend
Summer	91	225	291.7	0.2202	not significant upward
Summer	101	193	340.8	0.2856	not significant upward
Winter	96	171	315.9	0.2942	not significant upward
Winter	**130**	**299**	**496.9**	**0.2737**	**not significant upward**

Start Date	Last Date	Total Data	State	County	City
08-Jan-02	07-Mar-08	351	North Carolina	Lenoir	Kinston
21-Nov-01	27-Sep-08	423	South Carolina	Greenville	Taylors
20-Jan-02	26-Dec-08	411	Kentucky	Jefferson	Louisville
03-Nov-01	**10-Dec-10**	**529**	**Kentucky**	**Fayette**	**Lexington-Fayette**

Trend analysis performed on average monthly values.

$PM_{2.5}$ Nitrate Upward Trends

Month or Season	Number	Mann-Kendall Statistic	Standard Deviation	p-value	Trend
Spring	86	223	268.1	0.2028	not significant upward
Spring	**360**	**2216**	**2281.6**	**0.1657**	**not significant upward**
Winter	**130**	**328**	**496.9**	**0.2546**	**not significant upward**
Winter	**74**	**134**	**214.3**	**0.2659**	**not significant upward**
Winter	**129**	**337**	**491.2**	**0.2463**	**not significant upward**
Winter	**535**	**8362**	**4130.6**	**0.0215**	**significant upward**
Winter	**360**	**7222**	**2281.6**	**0.0008**	**significant upward**

Start Date	Last Date	Total Data	State	County	City
08-Jan-02	07-Mar-08	351	North Carolina	Lenoir	Kinston
20-Jul-94	**30-Dec-09**	**1475**	**North Carolina**	**Haywood**	**Not in a city**
03-Nov-01	**07-Jun-10**	**507**	**Kentucky**	**Kenton**	**Covington**
04-Apr-05	**10-Dec-10**	**327**	**Alabama**	**Russell**	**Phenix City**
03-Nov-01	**10-Dec-10**	**537**	**Kentucky**	**Boyd**	**Ashland**
02-Mar-88	**30-Dec-09**	**2285**	**Tennessee**	**Blount**	**Not in a city**
20-Jul-94	**30-Dec-09**	**1475**	**North Carolina**	**Haywood**	**Not in a city**

Trend analysis performed on average monthly values.

Other $PM_{2.5}$ Species Trends

Parameter	Trend	Fall	Spring	Summer	Winter
Ammonium Ion	not significant downward	9%	2%	6%	26%
	not significant upward	2%	9%	9%	17%
	significant downward	**68%**	**68%**	**64%**	**36%**
	significant upward				
Elemental Carbon	not significant downward	4%	**11%**	17%	**32%**
	not significant upward	13%	**28%**	17%	**21%**
	significant downward	2%	11%		4%
	significant upward	**47%**	17%	**32%**	9%
Organic Carbon	not significant downward	**19%**	**13%**	**15%**	**26%**
	not significant upward	**30%**	**32%**	**28%**	**11%**
	significant downward	15%	11%	4%	30%
	significant upward	2%	11%	19%	

Trend analysis performed on average monthly values.

Conclusions

- SO_2 and NO_x emissions in the Southeastern U.S. have dramatically decreased starting 2008
- These trends have been reflected in the regional $PM_{2.5}$ monitoring data, especially in the sulfate fraction
- These trends coincide with the implementation of CAIR, which significantly decreased the emissions allowances for SO_2 and NO_x

Questions?